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# Informational Complementarity

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**Abstract.** Many products have similar or common attributes and are thus correlated. We show that, when these attributes are uncertain for consumers, a complementarity effect can arise among competing products in the sense that the lower price of one product may increase the demands for the others. This effect occurs when consumers sequentially search for information about both common and idiosyncratic product attributes before purchase. We characterize the optimal search strategy for the correlated search problem, provide the conditions for the existence of the complementarity effect, and show that the effect is robust under a wide range of alternative assumptions. We further explore the implications of the effect for pricing. When firms compete in price, although product correlation may weaken differentiation between the firms, the complementarity effect owing to correlated search may raise equilibrium price and profit.

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## 1. Introduction

In many markets, different products that consumers consider purchasing have common or similar attributes. For example, many automobile manufacturers offer product lines consisting of models that share a brand image, technologies, aspects of design, and after-sales service. BMW cars are known for their performance, Mercedes for luxury, Volvo for safety, and Toyota for reliability, etc. Even products from competing brands may have common attributes. For example, electric cars produced by BMW and Mercedes originate in the same country and have similar engine technologies. Examples can be found in many other industries. Houses in the same neighborhood share characteristics in terms of transportation accessibility, quality of schools, and crime statistics. Manufacturers of organic light-emitting diode televisions, such as LG and Sony, use the same display technology and thus, offer similar image quality and viewing experiences. Business or economics doctoral students may look for jobs in technology companies, such as Amazon, Facebook, and Microsoft, which offer similar work environment and work-life balance compared with academic jobs.

Consumers can be faced with products sharing similar attributes, but they may often be uncertain about the value that these product attributes provide to them. They may then often spend considerable time gathering, processing, and understanding information

about products before making decisions. A 2010 survey by Zillow.com found that an average U.S. consumer spends 40 hours searching for information before purchasing a new home, 10 hours searching for information for a major home improvement or a car, 5 hours searching for information for a vacation or a mortgage, 4 hours searching for information for a computer, and 2 hours searching for information for a television set. Bronnenberg et al. (2016) find that consumers search extensively online before purchasing a camera and engage in 14 searches on average.

In this study, we examine a decision problem in which consumers choose one among multiple products with correlated uncertain information and may search for information about these alternatives before making a decision. In the process of information acquisition, new information about one product may change a consumer's preferences for other products that share similar attributes. For example, as a consumer researches a BMW electric car, she learns about the costs and benefits of owning an electric car (compared with a gasoline car). This information will change her preferences for all electric cars of other brands. We show that, although different alternatives in a choice set are naturally substitutes, their demands may exhibit complementary effects. In particular, lowering the price of one alternative can increase the demands for others that have common attributes.

The basic argument goes as follows. Consider a consumer who considers buying an electric car from either BMW or Mercedes, with an outside option of not buying anything (or perhaps, instead, buying a gasoline car). The two electric cars share similar technologies—notably electric propulsion, the exact benefits of which are unknown to the consumer a priori. Suppose initially that the prices of both cars are so high that the consumer will neither search for nor buy either of them. Now imagine that BMW lowers the price of its car. Two outcomes are then possible. In the first case, the lower BMW price prompts the consumer to start searching for information about the car. As she learns more about the BMW electric car, she may develop a strong preference for electric cars but not specifically for BMW (perhaps because of its unattractive exterior design). Thus, she decides to explore more electric cars and continues to search for information about Mercedes' version. She may eventually prefer the Mercedes and purchase it. In the second case, the lower BMW price does not motivate the consumer to inspect BMW right away. Instead, while keeping the attractive option of the BMW car in reserve, she can first inspect Mercedes given that she preferred Mercedes before her search. Again, she may eventually purchase Mercedes after the search. It is also possible that she will continue to search on BMW after Mercedes. To summarize, in both cases, the lower BMW price may actually increase the demand for Mercedes. The former case occurs when the consumer's prior preference for Mercedes is relatively weak, whereas the latter arises when her prior preference for Mercedes is relatively strong but not strong enough to induce her to search on Mercedes in the absence of BMW's price promotion. We term this demand complementarity effect "informational complementarity," which is the primary focus of this study.

We develop a stylized sequential search model that formalizes the above mechanism and allows us to explore the conditions under which informational complementarity can arise and its implications. Consumers are interested in buying one of two competing products, which are correlated through a common attribute. The benefits of this common attribute and the products' idiosyncratic attributes are initially uncertain to consumers. To make an informed decision, they need to gather information about these attributes. Information is costly to acquire, and consumers need to optimally determine the products to search on and when to stop searching and make a purchase decision. This problem belongs to a general class of *correlated bandits problems*, which are known to be very difficult to solve analytically. The well-known index policy has been shown to be optimal for independent bandits problems,<sup>1</sup> but it is not guaranteed to work

after relaxing the independence assumption. Despite this technical difficulty, we characterize the structure of a consumer's optimal search strategy and derive the necessary and sufficient conditions under which informational complementarity can arise. Our analysis suggests that this effect occurs when the search cost is not too high and the ex ante preferences for the two products are neither too strong nor too weak. When a consumer has a very strong preference for Mercedes, for example, lowering the price of BMW will only reduce the incentive to search on and eventually purchase Mercedes. When the preference for Mercedes is very weak, a price reduction in BMW will have no impact on the demand for Mercedes, because it does not enter the consumer's consideration set at all.

The informational complementarity effect has important implications for competitive pricing. We use a simple duopoly model to illustrate that product correlation can introduce two opposing effects. On one hand, the informational complementarity effect expands the search regions for competing products. This brings in new consumers who would never consider any of the products in the first place if they were independent. On the other hand, if the product attributes are correlated, then the competing products are less differentiated. If consumers find that the common attribute is negative after inspecting one product, then the negative impression can spill over to the correlated product, lowering the purchase likelihood for both. Both products then have less market power and suffer from fiercer price competition. The tradeoff between the two effects rests on the magnitude of the search cost. If the search cost is very low, the price competition is intensified to the extent that it outweighs the benefit of informational complementarity. The equilibrium price and profit are lower when products are correlated than when they are independent. If the search cost is higher but not too high, then the informational complementarity effect dominates the need to differentiate. Both equilibrium price and profit may become higher when products are correlated, which may, in turn, justify why firms may be willing to share similar attributes in the first place. This implies that, if the competing firms can collusively manipulate the information correlation between their products, they can make them complements rather than substitutes. Hence, there is a possibility for horizontal collusion via product information instead of price.

### 1.1. Related Literature

This study is closely related to the extensive research into optimal sequential search (notably, McCall (1970) and Weitzman (1979)) and its applications for pricing (e.g., Diamond 1971, Wolinsky 1986, Stahl 1989,

Anderson and Renault 1999), advertising (e.g., Anderson and Renault 2006, Mayzlin and Shin 2011), and product design (e.g., Kuksov 2004, Bar-Isaac et al. 2012). The basic premise of this literature is that consumers are uncertain about some attributes or their overall utility of a product. They can acquire information through costly search before they decide on which product to purchase. Most work assumes that all of the available information on a product will be revealed after one search action and that information is independent across products. We relax both assumptions in this study. Thus, our work is in line with the recent stream of research that allows information of a product to be revealed gradually over multiple search actions (e.g., Branco et al. 2012, Ke et al. 2016, Ke and Villas-Boas 2019). However, we allow for correlated product information by incorporating both common and idiosyncratic attributes for each product. To our knowledge, our study is the first study that presents both a general characterization and a complete characterization of consumers' optimal sequential search strategy with correlated product information.<sup>2</sup>

More broadly, our work is related to the literature on correlated learning and demand spillover. A large body of theoretical and empirical work focuses on the phenomenon of brand extension or umbrella branding (e.g., Wernerfelt 1988, Choi 1998, Erdem 1998, Cabral 2000), where multiproduct firms leverage the brand reputation of established products to signal the quality of new products. The basic idea is that consumers can use their experience or knowledge of an established product to infer the quality of an uncertain new one. More generally, consumers' experience of a product may lead them to learn about other related products (Hendricks and Sorensen 2009). Recent literature examines whether and how the marketing activities of a brand can indirectly affect competing brands. For example, firms that advertise their own products have been found to also benefit their competitors, because advertising can lead consumers to become aware of competing brands or prime them to think about the product category (Janakiraman et al. 2009, Anderson and Simester 2013, Lewis and Nguyen 2015, Sahni 2016, Shapiro 2018). Our work adds to these two research streams by showing that positive demand spillover can persist even when products are naturally substitutes because of the unit demands of consumers. The mechanism differs from those reported in the literature in that consumers actively acquire product information at some costs instead of passively receiving information without any effort. We find the similar insight that information from an already searched or experienced product has a positive impact on the other products, and we provide the novel insight that a product's demand can

be positively influenced by the option value of continuing the search with another product.

This paper also contributes to the important econometric literature that focuses on understanding and measuring demand complementarity among products (e.g., Manski and Sherman 1980, Train et al. 1987, Hendel 1999, Gentzkow 2007). Complementarity typically arises when consumers have multiunit demands, where the joint consumption of multiple products yields a greater utility than the sum of the consumption utilities of the individual products. However, when consumers have unit demands, complementarities between alternatives are generally ruled out in discrete choice models (McFadden 1978). One exception is the recent work by Fosgerau et al. (2017), who show that a demand complementarity effect can arise in a rational inattention model when information costs are modeled using a class of generalized entropies. Our work suggests an alternative mechanism that can lead to the demand complementarity effect, which is driven by consumers' costly acquisition of correlated product information.

The remainder of this paper is organized as follows. We present the main model in Section 2, and then, we characterize consumers' optimal search strategy and the informational complementarity effect in Section 3. In Section 4, we apply the framework to study imperfect price competition in a duopoly setting. In Section 5, we consider several alternative setups of the problem and find that the informational complementarity effect is robust across these extensions. We conclude the paper and suggest future research directions in Section 6.

## 2. A Model of Correlated Search

There are two products in the market indexed by  $i = 1, 2$ . Many real-world observations lead us to posit that the products can be represented by both common and idiosyncratic attributes. The distinction between these two types of attributes has long been used to study the human perception of related objects (e.g., Tversky 1977) and allows us to tractably model the phenomenon of product correlation. A representative consumer's utility of product  $i$  is given by

$$U_i = \alpha_i + X - p_i + \varepsilon_i, \quad (1)$$

where  $p_i$  is the price,  $X$  is the common attribute shared by the two products, and both  $\alpha_i$  and  $\varepsilon_i$  are idiosyncratic utilities for product  $i$ . The consumer knows  $p_i$  and  $\alpha_i$  a priori but does not know  $X$  and  $\varepsilon_i$  ( $i = 1, 2$ ). We assume that  $X$  follows distribution  $G$  with support in  $[\underline{X}, \bar{X}]$  and that  $\varepsilon_i$  follows distribution  $F$  with support in  $[\underline{\varepsilon}, \bar{\varepsilon}]$ , where  $\underline{X}$ ,  $\bar{X}$ ,  $\underline{\varepsilon}$ , and  $\bar{\varepsilon}$  can be finite or infinite.  $X$ ,  $\varepsilon_1$ , and  $\varepsilon_2$  are assumed to be independent.

To avoid trivialities, we assume that  $\text{Var}[X] > 0$  and  $\text{Var}[\varepsilon_i] > 0$ . We further assume that  $G$  and  $F$  do not depend on the prices  $p_1$  and  $p_2$ . Without loss of generality, we assume that  $E[X] = E[\varepsilon_i] = 0$  ( $i = 1, 2$ ). The outside option is assumed to be deterministic and known, with utility normalized to be zero. Both  $p_i$  and  $\alpha_i$  are known ex ante, and therefore, it is convenient to define the consumer's ex ante expected utility as  $u_i \equiv E[U_i] = \alpha_i - p_i$  and work with  $u_i$  in the analysis below.

The consumer searches for information about the two products sequentially before making a purchase decision. Each time the consumer searches on a product, she pays a search cost  $c > 0$  and discovers all of the available information about the product. Therefore, if she searches on product  $i$  first, she will discover both  $X$  and  $\varepsilon_i$ . At this time point, she remains uncertain about  $\varepsilon_j$ , the idiosyncratic attribute of product  $j$ . If she continues to search on product  $j$  by paying  $c$  again, she will further discover  $\varepsilon_j$ .<sup>3</sup> Notice that we have assumed that the consumer can learn  $X$  and  $\varepsilon_i$  separately after searching on product  $i$ . This corresponds to the interpretation that  $X$  and  $\varepsilon_i$  are different attributes of the product, and the consumer learns whether each attribute fits her need separately. In Section 5.4, we show that informational complementarity still arises under an alternative setting where  $X$  and  $\varepsilon_i$  cannot be identified separately. Following the majority of the literature (e.g., Weitzman 1979, Wolinsky 1986), we assume that the consumer has to search on a product before purchasing it. This is a reasonable assumption if we consider cases in which consumers have to pay travel costs to visit a store before making a purchase.<sup>4</sup>

The consumer conducts a sequential search to maximize her expected utility: she has to optimally decide which product to search on and when to stop searching at any time. The decision process lasts for at most three stages, and therefore, we can formulate the optimal search problem as a dynamic optimization problem in three stages and solve it by backward induction. In the last stage, after having searched on both products and discovered  $X$ ,  $\varepsilon_1$ , and  $\varepsilon_2$ , the consumer needs to decide which product to buy or whether to take the outside option. Her value function is then given by

$$V_2(X, \varepsilon_1, \varepsilon_2) = \max\{U_1, U_2, 0\} \\ = \max\{u_1 + X + \varepsilon_1, u_2 + X + \varepsilon_2, 0\}, \quad (2)$$

where  $X$ ,  $\varepsilon_1$ , and  $\varepsilon_2$  together are the state variables that characterize the consumer's current information.<sup>5</sup> Going back one stage, the consumer has already

searched on one product, say product  $i$ , and discovered  $X$  and  $\varepsilon_i$ . Her value function in this stage is

$$V_{1i}(X, \varepsilon_i) = \max\{u_i + X + \varepsilon_i, 0, -c \\ + E[V_2(X, \varepsilon_1, \varepsilon_2)|X, \varepsilon_i]\}, \text{ for } i \neq j = 1, 2. \quad (3)$$

The three terms inside the brackets are the utilities of purchasing product  $i$ , taking the outside option, and the conditional expected utility of continuing to search on product  $j$ , respectively. Notice that the information revealed by product  $i$  has implications on the expected utility of continuing to search on product  $j$ , because the attribute  $X$  is common to both products. Going back to the first stage, the consumer has not inspected any product. She needs to decide which product to search on first or whether to take the outside option to maximize her expected utility

$$V = \max\{0, -c + E[V_{11}(X, \varepsilon_1)], -c + E[V_{12}(X, \varepsilon_2)]\}, \quad (4)$$

where the three terms in the maximization on the right-hand side correspond to the (expected) utilities of taking the outside option, searching on product 1, and searching on product 2, respectively.

Thus far, we have laid out a consumer's sequential search problem with correlated product information and formulated it as a dynamic optimization problem. Table 1 summarizes all of the notations that have been introduced so far as well as those to be introduced in the next section.

We conclude this section by considering two benchmark cases in which a consumer makes static decisions. First, if there is no search cost,  $c = 0$ , then the consumer obtains all of the uncertain information  $(X, \varepsilon_1, \varepsilon_2)$  before purchase, leading to a static decision problem with complete information. The demand function of product  $i$  then becomes

$$D_i^0(u_i, u_j) = \Pr(U_i > U_j \text{ and } U_i > 0) \\ = \Pr(u_i + \varepsilon_i > u_j + \varepsilon_j \text{ and } u_i + X + \varepsilon_i > 0). \quad (5)$$

Clearly, as  $u_j$  increases, the condition in Equation (5) is less likely to be satisfied. Therefore,  $D_i^0(u_i, u_j)$  is a nonincreasing function of  $u_j$ . Intuitively, because products  $i$  and  $j$  are substitutes, when product  $j$  becomes more attractive because of a lower price, the demand of the rival product  $i$  will reduce. This result holds even though the two products are correlated, because the common features of the two cancel out.

**Table 1.** Summary of Notations

Notation	Description
<b>Primary parameters</b>	
$c$	Search cost
$F$	Distribution function for $\varepsilon_i$ with support on $[\underline{\varepsilon}, \bar{\varepsilon}]$
$G$	Distribution function for $X$ with support on $[\underline{X}, \bar{X}]$
<b>Secondary parameters</b>	
$u_0$	The utility at which a consumer is indifferent among inspecting product 1, inspecting product 2, and taking the outside option defined by $E[V_{1i}(X, \varepsilon_i)] _{u_1=u_2=u_0} = c$
$\bar{u}$	The utility at which a consumer is indifferent between inspecting a product and taking the outside option given no other products defined by $E[\max\{\bar{u} + X + \varepsilon_i, 0\}] = c$
$\underline{u}$	The lowest utility level of a product to ensure that it is still in a consumer’s consideration set defined by $\underline{u} \equiv \max\{\bar{u} + \underline{\varepsilon}, -\bar{X}\} - \varepsilon^*$
<b>Variables</b>	
$p_i$	Price of product $i$
$U_i$	A consumer’s utility of product $i$ , $U_i = \alpha_i + X - p_i + \varepsilon_i$
$u_i$	A consumer’s ex ante expected utility of product $i$ , $u_i = E[U_i] = \alpha_i - p_i$
$U_i^*$	Reservation value of product $i$ given $X$ known and $\varepsilon_i$ unknown, $U_i^* = u_i + X + \varepsilon^*$ with $\varepsilon^*$ defined by $\int_{\varepsilon^*}^{\bar{\varepsilon}} (\varepsilon - \varepsilon^*) dF(\varepsilon) = c$
$V_{1i}(X, \varepsilon_i)$	Value function at stage 2—a consumer’s maximum expected utility conditioning on that she has inspected product $i$ and learned $X$ and $\varepsilon_i$

The second case captures the situation in which the search cost is infinitely high,  $c = \infty$ . Here, the consumer never searches and thus, never buys. Therefore, the demand for both products is always zero. Even if we allow the consumer to make a purchase before search, her decision only relies on her expected utilities. We have the demand function as

$$D_i^\infty(u_i, u_j) = \mathbb{1}\{u_i > u_j \text{ and } u_i > 0\}, \quad (6)$$

where  $\mathbb{1}\{\cdot\}$  is the indicator function. Obviously,  $D_i^\infty(u_i, u_j)$  is a nonincreasing function of  $u_j$ .

These observations illustrate that the correlation between products does not influence the substitution pattern of the consumer’s choice behavior when there is either complete information or no information at all. Products are always substitutes. In the next section, we demonstrate that, when consumers engage in costly search for information and when the search cost is in the intermediate range (i.e.,  $0 < c < \infty$ ), this conclusion no longer holds.

### 3. Characterization of Informational Complementarity

In this section, we present the main result of the study. Our first step is to characterize the optimal search strategy. From this, we can identify the conditions under which informational complementarity can arise. We conclude this section with a simple example of two-point distributions to illustrate the solution and the effect.

#### 3.1. Optimal Search Strategy

To derive the optimal search strategy, we first consider an elementary problem. This is a reduced search

problem in which a consumer has only two options—either to search on product  $i$  or to take the outside option. Product  $j$  is absent from the consumer’s consideration for search or purchase. An equivalent way to interpret this reduced problem is to assume that  $u_j = -\infty$ . The optimal search strategy for this reduced problem is simply to search on product  $i$  if and only if  $u_i \geq \bar{u}$ , where  $\bar{u}$  is defined as follows:

$$E[\max\{\bar{u} + X + \varepsilon_i, 0\}] = c. \quad (7)$$

The left-hand side is the expected gain from searching on product  $i$  over all possible values of  $X$  and  $\varepsilon_i$ , and the right-hand side is the search cost. Thus,  $\bar{u}$  is the threshold utility at which the consumer is indifferent between searching on product  $i$  and taking the outside option in the absence of product  $j$ .

If the two products were independent, then separately considering the above reduced problem for each product would be sufficient to derive the optimal index strategy (known as Pandora’s rule from Weitzman in the search literature). The central idea of this strategy is to decompose the complex  $N$  alternative problem into a set of  $N$  simpler reduced problems. However, the violation of independence assumption here does not allow us to apply this strategy. When the two products correlate, we need to consider the impact of product  $j$  when the consumer contemplates searching on product  $i$ .

Suppose now that, after the consumer has inspected product  $i$  in the first stage, she discovers both the common and idiosyncratic attributes,  $X$  and  $\varepsilon_i$ . Conditional on the common attribute  $X$ , there is no dependence between the two products, and therefore,

the consumer’s subsequent optimal search problem can be characterized by Pandora’s rule. In particular, she continues to inspect project  $j$  if and only if her maximum utility from product  $i$  and the outside option is less than the threshold  $U_j^*$ , which is the reservation utility that makes her indifferent between continuing to search on product  $j$  and adopting an option with utility  $U_j^*$ . We can write  $U_j^* = u_j + X + \varepsilon^*$ , where  $\varepsilon^*$  is defined by the following equation:

$$E[\max\{\varepsilon - \varepsilon^*, 0\}] = c. \tag{8}$$

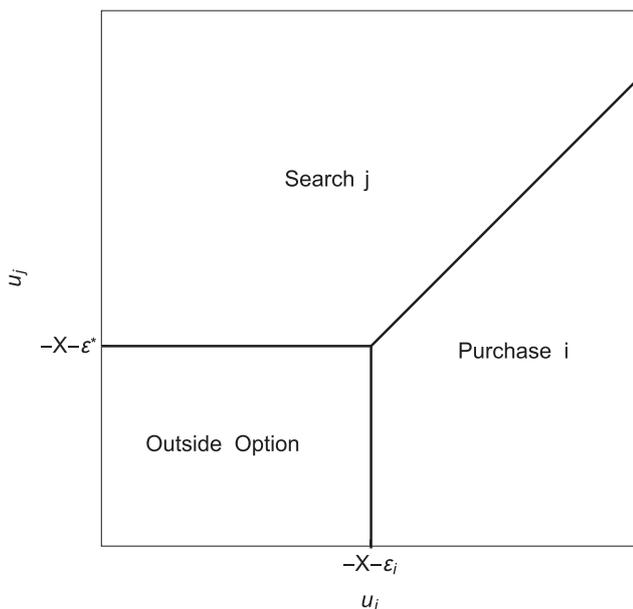
Following the standard assumption that  $c$  is not very large (e.g., Wolinsky 1986, Anderson and Renault 1999),  $\varepsilon^*$  is well defined by Equation (8). Figure 1 illustrates the optimal search strategy in the second stage.

The consumer continues to inspect product  $j$  if and only if  $U_j^* = u_j + X + \varepsilon^* \geq \max\{u_i + X + \varepsilon_i, 0\}$  or equivalently,

$$u_j \geq \max\{u_i + \varepsilon_i, -X\} - \varepsilon^*. \tag{9}$$

Notice that the right-hand side of the inequality (9) weakly increases with  $\varepsilon_i$  and weakly decreases with  $X$ , and thus, it takes the minimum value when  $\varepsilon_i = \underline{\varepsilon}$  and  $X = \bar{X}$ . Intuitively, continuing to search on product  $j$  is most attractive to a consumer if the consumer receives the most negative signal on the idiosyncratic attribute of product  $i$  and the most positive signal on the common attribute of the two products. This implies that, given  $u_i$ , when  $u_j < \max\{u_i + \underline{\varepsilon}, -\bar{X}\} - \varepsilon^*$ , the consumer will never continue to search on product  $j$  regardless of the realized values of  $X$  and  $\varepsilon_i$  from her

**Figure 1.** Illustration of a Consumer’s Optimal Search Strategy in the Second Stage



first search. The decision between searching on product  $i$  first and taking the outside option is then just equivalent to the reduced problem with  $u_j = -\infty$ . This observation leads us to identify the point at which the consumer is just willing to search on product  $i$  first because of the option value of continuing to search on product  $j$ .

More precisely, we fix the prior expected utility of product  $i$  at  $u_i = \bar{u}$  identified by assuming  $u_j = -\infty$  and then, find the smallest value of  $u_j$  that satisfies Equation (9) over all possible realizations of  $(X, \varepsilon_i)$ . This value,  $u_j = \underline{u}$ , is then defined as follows:

$$\underline{u} \equiv \max\{\bar{u} + \underline{\varepsilon}, -\bar{X}\} - \varepsilon^*. \tag{10}$$

In the online appendix (proof of Theorem 1), we prove that, if  $u_j < \underline{u}$ , the consumer’s optimal search problem reduces to that found in the absence of product  $j$ . Thus, the consumer will neither search on nor purchase product  $j$ . If  $u_i \geq u_j \geq \underline{u}$ , it is possible that the consumer will continue to search on product  $j$  after first searching on product  $i$ . Last, if  $u_j > u_i$ , it is optimal for the consumer to either first search on product  $j$  or take the outside option.

The option value of continuing to inspect product  $j$  makes the search of product  $i$  in the first stage more attractive. Let  $\tilde{u}(u_j)$  denote the indifference curve between first inspecting  $i$  and taking the outside option. From Equation (4), this indifference curve is defined by

$$E[V_{1i}(X, \varepsilon_i)|u_i = \tilde{u}(u_j)] = c.$$

The last useful threshold that we define is  $u_0$  using  $\tilde{u}(u_0) = u_0$  or equivalently,

$$E[V_{1i}(X, \varepsilon_i)|u_1 = u_2 = u_0] = c. \tag{11}$$

By the definition, given  $u_1 = u_2 = u_0$ , a consumer will be indifferent about inspecting product 1, inspecting product 2, or taking the outside option in the first stage.

We are now prepared to characterize the consumer’s optimal search strategy, which is summarized by the following theorem. The proof is given in the online appendix.

**Theorem 1** (Optimal Search Strategy).

1. If  $\underline{u} \geq \bar{u}$ , it is optimal to first search on product  $i$  if and only if  $u_i \geq \max\{u_j, \bar{u}\}$  for  $i \neq j = 1, 2$ .
2. If  $\underline{u} < \bar{u}$ , it is optimal to first search on product  $i$  if  $u_i \geq \max\{u_j, \tilde{u}(u_j)\}$  for  $i \neq j = 1, 2$ . Furthermore, the indifference curve between searching on  $i$  and taking the outside option  $\tilde{u}(u_j) = \bar{u}$  for  $u_j \leq \underline{u}$  and  $\tilde{u}(u_j)$  decreases with  $u_j$  for  $u_0 \geq u_j > \underline{u}$ .

We can consider two cases. First, if  $\underline{u} \geq \bar{u}$ , we can fully characterize the optimal search strategy, which

is equivalent to Pandora’s rule (or index policy) under the independence assumption (i.e., without information correlation between the two products). Figure 2(a) illustrates the optimal search strategy in the first stage. Second, if  $\underline{u} < \bar{u}$ , then the optimal search strategy has a more complex threshold structure. Figure 2(b) illustrates this strategy in the first stage. The consumer never inspects product 1 in either stage when  $u_1 < \underline{u}$ . However, when  $u_1 \in [\underline{u}, u_0]$ , there is a positive probability that the consumer will inspect product 1 in the second stage, and thus, inspecting product 2 becomes more attractive in the first stage relative to the outside option. Therefore, as we increase  $u_1$  above  $\underline{u}$ , we can see from Figure 2(b) that the indifference curve between search 2 and the outside option falls below  $\bar{u}$ .

**3.2. Informational Complementarity**

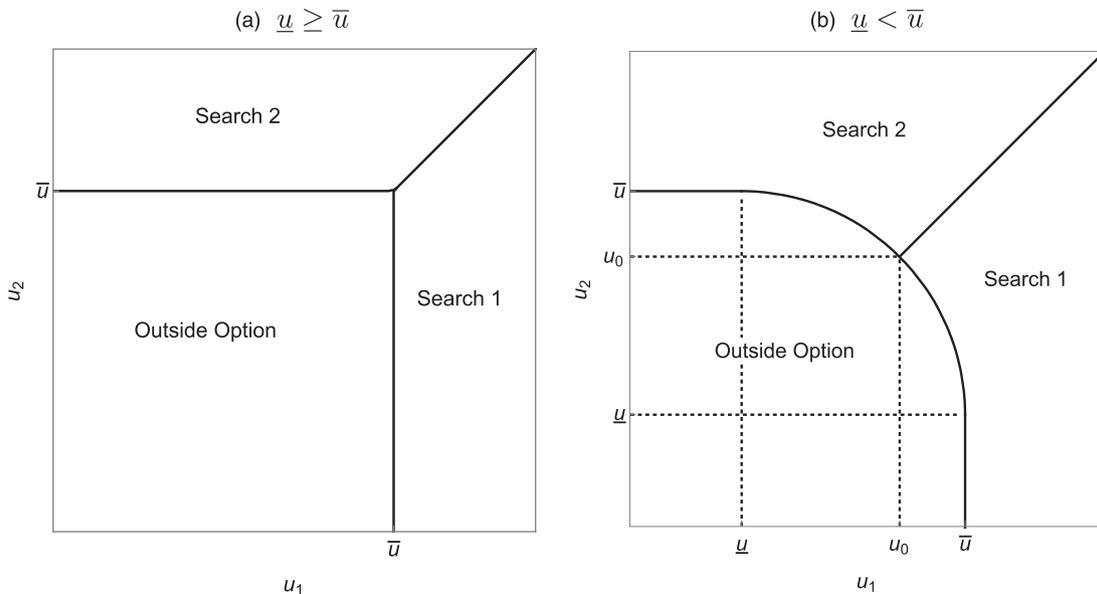
We have identified the optimal search strategy of a consumer faced with correlated products (a summary of all important notations introduced so far is provided in Table 1). Based on this strategy, we are now in a position to characterize the demand functions of the two products and explore the substitution pattern between them. The demand for product  $i$  can be written as follows:

$$\begin{aligned}
 D_i(u_i, u_j) &= \mathbb{1}_{\{E[V_{1i}(X, \varepsilon_i)] \geq c\}} \mathbb{1}_{\{u_i \geq u_j\}} \Pr(u_i + X + \varepsilon_i \\
 &\geq \max\{u_j + X + \min\{\varepsilon_j, \varepsilon^*\}, 0\}) \\
 &+ \mathbb{1}_{\{E[V_{1j}(X, \varepsilon_j)] \geq c\}} \mathbb{1}_{\{u_j > u_i\}} \Pr(u_i + X \\
 &+ \min\{\varepsilon_i, \varepsilon^*\} \geq \max\{u_j + X + \varepsilon_j, 0\}). \quad (12)
 \end{aligned}$$

The demand for product  $i$  can be decomposed into two components: one from inspecting product  $i$  first and the other from inspecting product  $j$  first. In the first case, the consumer searches on product  $i$  first if and only if  $E[V_{1i}(X, \varepsilon_i)] \geq c$  and  $u_i \geq u_j$ . After the search of product  $i$ ,  $X$  and  $\varepsilon_i$  are revealed, and she decides whether to continue to search on product  $j$ . This continuation problem is a standard sequential search problem without interproduct correlations. Armstrong (2017) and Choi et al. (2018) show that, when consumers conduct a sequential search before purchase à la Weitzman (1979), the resulting demand system is equivalent to a static discrete choice model if one defines the “equivalent utility” for product  $j$  as  $\min\{U_j, U_j^*\} = u_j + X + \min\{\varepsilon_j, \varepsilon^*\}$ . Therefore, given that a consumer has inspected product  $i$  and discovered  $X$  and  $\varepsilon_i$ , the probability that she will purchase product  $i$  is  $\Pr(u_i + X + \varepsilon_i \geq \max\{u_j + X + \min\{\varepsilon_j, \varepsilon^*\}, 0\} | X, \varepsilon_i)$ , which includes the possibility that she purchases product  $i$  immediately without continuing to search and that she returns to purchase product  $i$  after inspecting product  $j$ . In the second case, the consumer first inspects product  $j$  if and only if  $E[V_{1j}(X, \varepsilon_j)] \geq c$  and  $u_j > u_i$ .<sup>6</sup> After inspecting product  $j$  and discovering  $X$  and  $\varepsilon_j$ , the consumer purchases product  $i$  with the probability  $\Pr(u_i + X + \min\{\varepsilon_i, \varepsilon^*\} \geq \max\{u_j + X + \varepsilon_j, 0\} | X, \varepsilon_j)$ .

Based on Equation (12) and the consumer’s optimal search strategy characterized by Theorem 1, we can derive our main result on informational complementarity, which is summarized by the following theorem. The proof is given in the online appendix.

**Figure 2.** Illustration of a Consumer’s Optimal Search Strategy in the First Stage



**Theorem 2** (Informational Complementarity).

1. If  $0 < c < E[\varepsilon] - \underline{\varepsilon}$ , then  $\bar{u} > \underline{u}$ , and complementarity effect arises when  $u_i \in (\underline{u}, \bar{u})$ :  $D_i(u_i, u_j)$  first jumps from zero to a positive level and then, decreases with  $u_j$ . There is no complementarity for  $u_i \notin (\underline{u}, \bar{u})$ :  $D_i(u_i, u_j)$  always weakly decreases with  $u_j$ .

2. Otherwise, we have that  $\bar{u} \leq \underline{u}$ , and there is no complementarity effect:  $D_i(u_i, u_j)$  always weakly decreases with  $u_j$ .

Theorem 2 fully characterizes the conditions under which the informational complementarity effect can arise. Given the uncertain common attribute  $X$ , the demand for product  $i$  will first decrease and then, jump with the price of product  $j$  if and only if the search cost is positive but not prohibitively high and the consumer's ex ante utility of product  $i$  is neither too weak nor too strong:  $u_i \in (\underline{u}, \bar{u})$ . Notice that here we only consider one single consumer who may produce a discrete jump in her demand. If we consider a market populated by ex ante heterogenous consumers, as in Section 4 below, then the jumps in consumer demand can aggregate into a smooth function—the aggregated demand  $D_i(u_i, u_j)$  can first increase and then, decrease with  $u_j$ .

To understand these conditions, notice that the condition on the search cost for informational complementarity to arise is generally very weak—the condition  $0 < c < E[\varepsilon] - \underline{\varepsilon}$  is equivalent to  $\varepsilon^* \in (\underline{\varepsilon}, \bar{\varepsilon})$ , which ensures that, after inspecting one product, the consumer will continue to inspect the other product with a positive probability. If the distribution of  $\varepsilon$  has an infinite lower support such that  $\underline{\varepsilon} = -\infty$ , then the condition is always satisfied as long as  $c > 0$ .

Next, we can examine why the ex ante preference  $u_i$  needs to fall into an intermediate range for informational complementarity to occur. When the ex ante utility is too weak,  $u_i \leq \underline{u}$ , product  $i$  is out of the consumer's consideration set, and thus, the demand for product  $i$  is always zero regardless of the preference (and price) of the alternative product. However, at the other extreme, when the consumer has a very strong preference,  $u_i \geq \bar{u}$ , it is always optimal for her to search on either product  $i$  or product  $j$ . An increase in  $u_j$  (say by reducing its price) will only make it more attractive to inspect and buy product  $j$ . Consequently, the demand for product  $i$  always decreases with  $u_j$  or equivalently, increases with the price of product  $j$ . It is only when the consumer's expected utility of product  $i$  is in an intermediate range,  $u_i \in (\underline{u}, \bar{u})$ , that the complementarity effect arises. This effect can arise in two cases.

First,  $u_i \in (\underline{u}, u_0]$ . When  $u_j$  is relatively low, a consumer will take the outside option immediately as shown in Figure 2. As  $u_j$  increases, product  $j$  becomes more attractive, and it becomes optimal for the

consumer to inspect this product first; with a positive probability, it turns out that she does not particularly like its idiosyncratic attribute that much but really likes the attribute  $X$ , which is common to both products, and this induces her to continue to inspect product  $i$  and provides a positive probability that she will eventually purchase product  $i$ .

Second,  $u_i \in (u_0, \bar{u})$ . Similarly, when  $u_j$  is relatively low, a consumer will take the outside option right away. As  $u_j$  increases, product  $j$  becomes more attractive, which makes the entire product category more attractive. It is optimal for the consumer to inspect product  $i$  first in this case, because  $u_i > u_j$ . Thus, when  $u_j$  is relatively low, product  $i$  is not attractive enough to induce the consumer to search; in contrast, when  $u_j$  is relatively high, the consumer has enough incentive to search on product  $i$ , because the option value of continuing to inspect product  $j$  makes searching on product  $i$  in the first stage more attractive.

Last, it is worth pointing out that the demand complementarity effect may occur in a more general setting than that considered here. Along the same line of the proof of Theorem 2, one can show that a sufficient condition for demand complementarity to arise is the violation of the independence from the irrelevant alternatives condition (IIA) for search. Luce (1959) derived the logit model based on the IIA condition for choice—a consumer's probability of choosing one alternative over another does not depend on the presence or absence of other alternatives. The IIA condition for search can be defined similarly—a consumer's decision to search on an alternative or take the outside option does not depend on the presence or absence of another alternative.

Notice that, in the original framework with independent products of Weitzman (1979), the IIA condition for search is satisfied.<sup>7</sup> Armstrong (2017) and Choi et al. (2018) show that the demand system under this framework is equivalent to a static discrete choice model, which rules out demand complementarity across alternatives. In contrast, in our main model, Figure 2(b) shows that the IIA condition for search is violated, giving rise to the complementarity effect. Other scenarios in which this condition is violated can be identified, such as that in Section 5.2, where we consider a setting in which the consumer's search order for the two products is exogenously fixed. We find that the demand complementarity effect can arise even when the two products are independent (and indeed, the complementarity effect becomes stronger with correlated products).<sup>8</sup>

**3.3. An Example: Two-Point Distribution**

To illustrate the main results, we consider a simple example where both  $X$  and  $\varepsilon_i$  follow two-point distributions. Specifically, we assume that  $X$  takes the

value of either  $-\beta$  or  $\beta$  with equal probability and that  $\varepsilon_i$  equals either  $-1$  or  $1$  with equal probability. According to Theorem 2, to ensure that  $\bar{u} > \underline{u}$ , we need  $c < 1$ . Following Equations (7) and (10), we can derive the closed forms of  $\bar{u}$  and  $\underline{u}$  that characterize the informational complementarity effect.

$$\begin{aligned} \text{If } \beta \leq 1, \bar{u} &= \begin{cases} 4c - \beta - 1, & c \leq \frac{1}{2}\beta \\ 2c - 1, & \frac{1}{2}\beta < c \leq 1 - \frac{1}{2}\beta \\ \frac{1}{3}(4c - \beta - 1), & 1 - \frac{1}{2}\beta < c < 1, \end{cases} \\ \text{and } \underline{u} &= \begin{cases} 2c - \beta - 1, & c \leq 1 - \frac{1}{2}\beta \\ \frac{1}{3}(10c - \beta - 7), & 1 - \frac{1}{2}\beta < c < 1. \end{cases} \\ \text{If } \beta > 1, \bar{u} &= \begin{cases} 4c - \beta - 1, & c \leq \frac{1}{2} \\ 2c - \beta, & \frac{1}{2} < c \leq \beta - \frac{1}{2} \\ \frac{1}{3}(4c - \beta - 1), & \beta - \frac{1}{2} < c < 1, \end{cases} \\ \text{and } \underline{u} &= \begin{cases} 2c - \beta - 1, & c \leq \frac{1}{2} \\ 4c - \beta - 2, & \frac{1}{2} < c \leq \beta - \frac{1}{2} \\ \frac{1}{3}(10c - \beta - 7), & \beta - \frac{1}{2} < c < 1. \end{cases} \end{aligned}$$

Figure 3 illustrates the demand function  $D_i(u_i, u_j)$  under  $c = 0.5$  and  $\beta = 1$ . We can see that informational complementarity arises in Figure 3 when  $u_2$  is in the intermediate range ( $u_2 = -0.5$  and  $u_2 = 0$ ). Because the consumer's ex ante utility of product 1,  $u_1$ , increases, the purchase likelihood of product 2 (indicated by the dashed lines in Figure 3) first jumps from zero to a positive level and then, decreases. If the ex ante

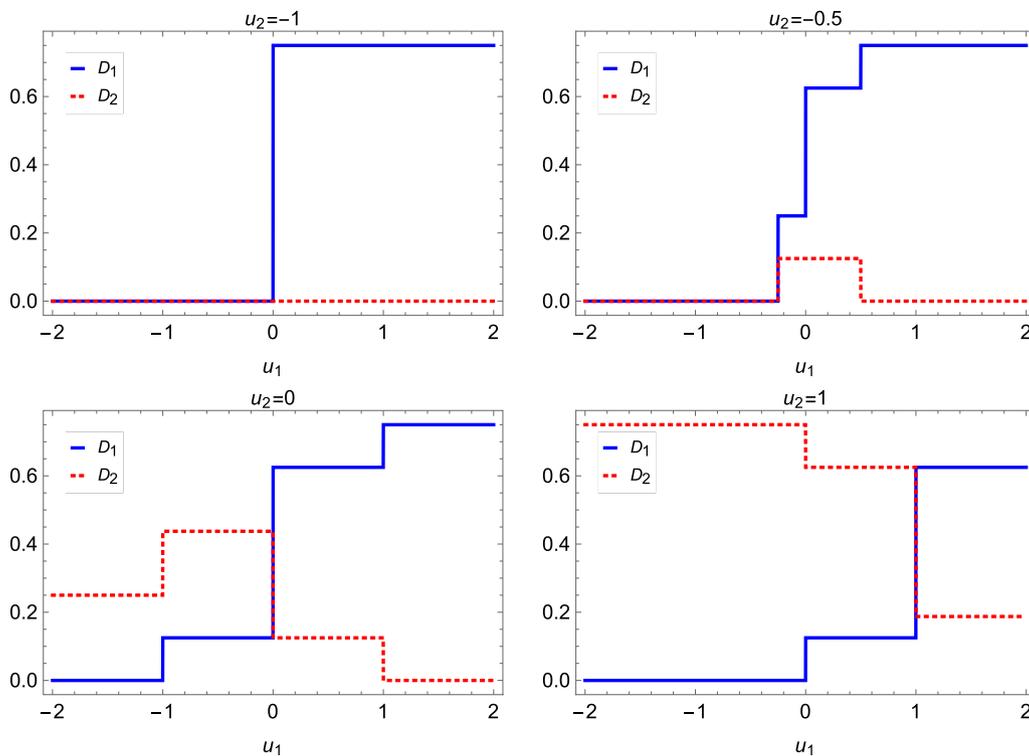
preference for product 2 is very weak ( $u_2 = -1$ ), its demand is always 0 as shown in the upper left panel of Figure 3. In contrast, if the ex ante preference for product 2 is very strong ( $u_2 = 1$ ), its demand follows the standard downward-sloping pattern as shown in the lower right panel of Figure 3.

#### 4. Competitive Pricing Under Correlated Search

We have shown that competing products may exhibit informational complementarity through consumers' correlated searches, taking prices as given. A natural question to ask is how this mechanism will affect firms' pricing behaviors under competition: will competing firms prefer a higher correlation between their products or no correlation? We address this by comparing the equilibrium price and profit when products are correlated and when they are independent.

To set up the analysis, let us consider a market populated by a unit mass of consumers who have a unit demand. The two products available in the market are owned by two firms, which compete by setting publicly observable prices,  $p_1$  and  $p_2$ . Therefore, consumers are informed about the prices before searching, and they search to acquire information about product attributes. This assumption is consistent with our consumer search model in the previous section, and it fits well with the setting of online shopping, where consumers can first easily browse

Figure 3. (Color online) Demand of Two Products as a Function of  $u_1$  (for  $c = 0.5$  and  $\beta = 1$ )



the prices of many products with little cost before clicking on each one to obtain detailed product information (Choi et al. 2018).<sup>9</sup> The marginal costs of production for both products are the same and normalized to zero.

Even when the products are independent, it is generally difficult to obtain closed form solutions to the equilibrium prices in a duopoly market with consumer search (Choi et al. 2018). The complexity stems from the “returning demand”—consumers who return to buy from the first firm after visiting both firms in the market.<sup>10</sup> To keep the analysis tractable, we impose specific distributional assumptions to eliminate returning demand in a duopoly setting.

We build on the discrete setup in Section 3.3 and assume that  $\beta = 1$  and  $c \leq 1/3$ . Recall that a consumer’s ex ante utility of product  $i$  is  $u_i = \alpha_i - p_i$ . We assume that consumers are ex ante heterogeneous in  $\alpha_1$  and  $\alpha_2$ , which are uniformly and independently distributed in  $[\underline{\alpha}, \bar{\alpha}]$ . The lower bound on  $\alpha_i$  is assumed to be sufficiently small,  $\underline{\alpha} \leq -2$ , so that, even with positive signals on both  $X$  and  $\varepsilon_i$ , some consumers do not purchase product  $i$ . The upper bound on  $\alpha_i$  is assumed to be 0,  $\bar{\alpha} = 0$ , to simplify the analysis. These assumptions imply that we are interested in a market in which consumers have relatively pessimistic beliefs about both products a priori. Thus, a sufficiently large segment of consumers is subject to the informational complementarity effect. Under these assumptions,  $u_i = \alpha_i - p_i \leq 0$  for any  $\alpha_i \in [\underline{\alpha}, \bar{\alpha}]$ , because firm  $i$  will not price below the marginal cost, which is normalized to be 0. Hence, for product  $i$  to be chosen, the realizations of both  $X$  and  $\varepsilon_i$  must be positive. That is,  $U_i = \alpha_i - p_i + X + \varepsilon_i > 0$  only if  $X = \varepsilon_i = 1$ . This substantially simplifies the calculation of firms’ demand functions by eliminating the returning demand—a consumer will buy product  $i$  after search if she receives positive signals about both  $X$  and  $\varepsilon_i$ ; otherwise, she will never buy the product.<sup>11</sup> Next, we analyze the benchmark case when the two products are independent, and then, we move on to the equilibrium analysis of the correlated case.

**4.1. Independent Case**

In this benchmark case, we modify the main model by assuming that product  $i$  has two idiosyncratic attributes,  $X_i$  and  $\varepsilon_i$ , where  $X_1, X_2, \varepsilon_1$ , and  $\varepsilon_2$  are independent. The optimal search rule is known to follow an index policy or Pandora’s rule. Specifically, the reservation utility of product  $i$  is  $\alpha_i - p_i - \bar{u}$ , where  $\bar{u}$  is defined by Equation (7). A consumer of type  $(\alpha_1, \alpha_2)$  first inspects product  $i$  if and only if  $\alpha_i - p_i - \bar{u} \geq \max\{\alpha_j - p_j - \bar{u}, 0\}$  or equivalently,  $\alpha_i - p_i \geq \max\{\alpha_j - p_j, \bar{u}\}$ . Given our distributional assumption, it is straightforward that  $\bar{u} = 4c - 2 \leq 0$ .

Consider a consumer who first inspects product  $i$ . This implies that  $\alpha_i - p_i \geq \max\{\alpha_j - p_j, \bar{u}\}$ . With probability 1/4, the outcome is  $(X_i, \varepsilon_i) = (1, 1)$ , under which case she will purchase product  $i$  right away, because  $U_i = \alpha_i - p_i + 2 \geq \max\{\alpha_j - p_j, \bar{u}\} + 2 \geq \max\{\alpha_j - p_j - \bar{u}, 0\}$ . With probability 3/4, the realizations will discourage her from buying the product. The question then is whether to continue to inspect product  $j$  or take the outside option. Applying the search rule, continuing to search is optimal as long as  $\alpha_j - p_j > \bar{u} = 4c - 2$ . Conditional on the second search, product  $j$  will be purchased only if  $(X_j, \varepsilon_j) = (1, 1)$ , which occurs with probability 1/4.

A symmetric equilibrium price  $p_{ind}^*$ , if it exists, must lie within  $[0, -\bar{u}]$ ; otherwise, both products will be dominated by the outside option. To derive the equilibrium price, we fix the price of firm 2 at the equilibrium price  $p_2 = p_{ind}^*$  and solve for firm 1’s pricing problem. Figure 4(a) illustrates the demand for firm 1 from two consumer segments.<sup>12</sup> Notice that consumers distribute uniformly in the square of  $u_1 \in [\underline{\alpha} - p_1, -p_1]$  and  $u_2 \in [\underline{\alpha} - p_{ind}^*, -p_{ind}^*]$ . The area of  $S'_{ind}$  represents the consumer segment that inspects product 1 first, and as discussed above, one-quarter of them will eventually purchase it; the area of  $S''_{ind}$  represents the consumer segment that inspects product 2 first and continues to inspect product 1, and as discussed above,  $3/4 \times 1/4 = 3/16$  of them will eventually purchase product 1. Therefore, firm 1’s demand is equal to  $1/4 \cdot S'_{ind} + 3/16 \cdot S''_{ind}$ . Given these consumer demands, we can derive the equilibrium price  $p_{ind}^*$  as follows:

$$p_{ind}^* = \arg \max_{p_1} \Pi_{ind}(p_1, p_{ind}^*)$$

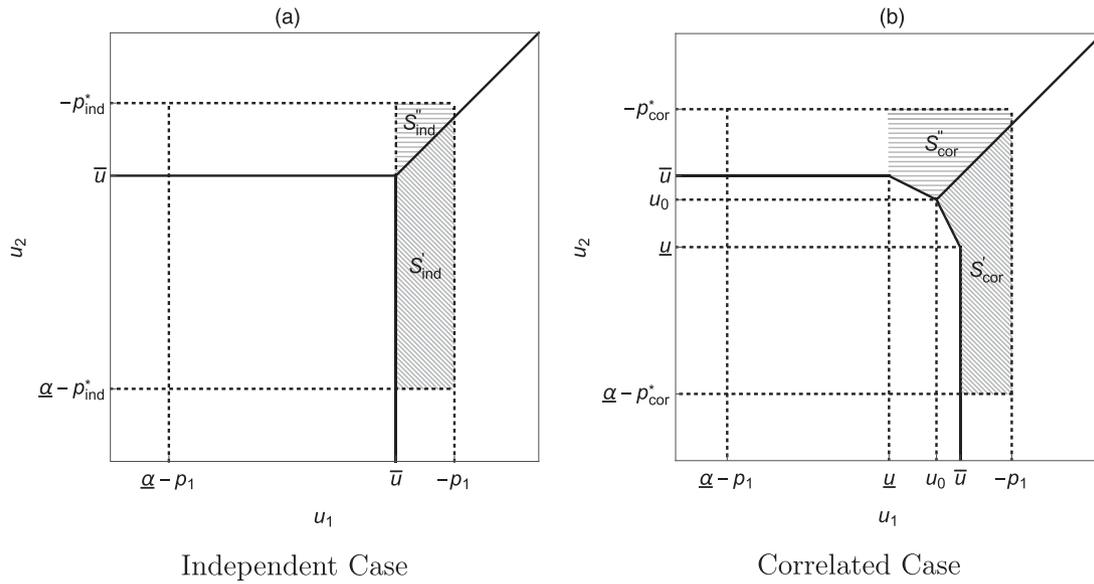
$$= \arg \max_{p_1} p_1 \left[ \frac{1}{4} S'_{ind}(p_1, p_{ind}^*) + \frac{3}{16} S''_{ind}(p_1, p_{ind}^*) \right].$$

In the online appendix, we provide closed form expressions of product demands and equilibrium price.

**4.2. Correlated Case**

When the products are correlated, we can derive the search thresholds following Section 3.3, with  $\varepsilon^* = 1 - 2c$ ,  $u_0 = \frac{10}{3}c - 2$ ,  $\bar{u} = 4c - 2$ , and  $\underline{u} = 2c - 2$ . Consider a consumer who first inspects product  $i$ . By Theorem 1, this implies that  $\alpha_i - p_i \geq \max\{\alpha_j - p_j, u_0\}$ . With probability 1/4, the outcome is  $(X, \varepsilon_i) = (1, 1)$ , under which case the consumer will purchase it right away, because  $U_i = \alpha_i - p_i + 2 \geq \max\{\alpha_j - p_j, u_0\} + 2 \geq \max\{\alpha_j - p_j + X + \varepsilon^*, 0\}$ . Other realizations, which occur with probability 3/4, will discourage her from buying the product. The question is then again whether to continue to inspect product  $j$  or leave the market. Continuing to search is optimal if and only if two conditions are met. First,  $(X, \varepsilon_i) = (1, -1)$  after the first search, which occurs with probability 1/4.<sup>13</sup>

**Figure 4.** Illustration of Firm 1’s Demand from Two Consumer Segments Under Independent and Correlated Cases



Notes. The solid lines represent the boundaries that correspond to a consumer’s optimal search strategy. (a) Independent case. (b) Correlated case.

Second,  $\alpha_j - p_j + X + \varepsilon^* \geq 0$ , or equivalently,  $\alpha_j - p_j \geq -1 - \varepsilon^* = \underline{u}$ . Conditional on the second search, product  $j$  will be purchased if  $\varepsilon_j = 1$ , which occurs with probability  $1/2$ .

We again look for symmetric price equilibrium and denote the equilibrium price as  $p_{cor}^*$ . This includes two possibilities. First, the equilibrium price  $p_{cor}^*$  lies within  $[0, -\bar{u}]$ , which is similar to the independent case. Second, it is also possible that  $p_{cor}^* > -\bar{u}$ , resulting in a smaller search region but a higher margin. Next, we derive the equilibrium for the first case, which exists for any  $c \leq 1/3$ , and in the online appendix, we rule out the second case given  $c \leq 1/3$ . Figure 4(b) illustrates the demand for firm 1 from the two consumer segments given  $p_2 = p_{cor}^*$ . The area of  $S'_{cor}$  represents the consumer segment that inspects product 1 first, and as discussed above,  $1/4$  of them will eventually purchase it; the area of  $S''_{cor}$  represents the consumer segment that inspects product 2 first and continues to inspect product 1, and as discussed above,  $1/4 \times 1/2 = 1/8$  of them will eventually purchase product 1. Therefore, firm 1’s demand is equal to  $1/4 \cdot S'_{cor} + 1/8 \cdot S''_{cor}$ . Notice that, compared with Figure 4(a), both consumer segments have expanded owing to the informational complementarity effect.

Given these consumer demands, we can derive the equilibrium price  $p_{ind}^*$  as follows:

$$\begin{aligned}
 p_{cor}^* &= \arg \max_{p_1} \Pi_{cor}(p_1, p_{cor}^*) \\
 &= \arg \max_{p_1} p_1 \left[ \frac{1}{4} S'_{cor}(p_1, p_{cor}^*) + \frac{1}{8} S''_{cor}(p_1, p_{cor}^*) \right].
 \end{aligned}$$

In the online appendix, we provide closed form expressions of product demands and equilibrium price.

### 4.3. Comparison

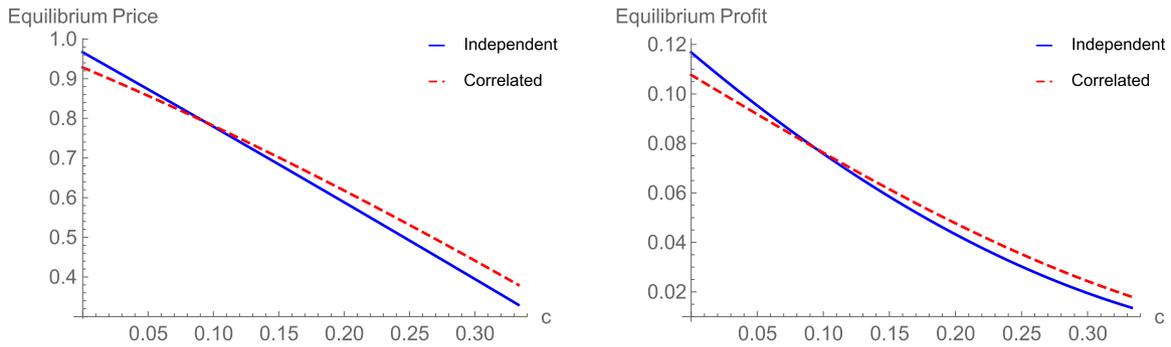
We can now compare the equilibrium prices and profits of the two cases. Our focus is on the comparative statistics with respect to the search cost  $c$ . The following theorem summarizes the results.

**Theorem 3.** *There exists a threshold  $\hat{c}$  such that, if  $c \leq \hat{c}$ , then  $p_{ind}^* \geq p_{cor}^*$  and  $\Pi_{ind}^* \geq \Pi_{cor}^*$ ; otherwise, if  $c > \hat{c}$ , then  $p_{ind}^* < p_{cor}^*$  and  $\Pi_{ind}^* < \Pi_{cor}^*$ .*

The proof with the closed form solution to the threshold  $\hat{c}$  is provided in the online appendix. Figure 5 compares the equilibrium prices and profits under the two cases as the search cost  $c$  varies. Notice that, in both independent and correlated cases, the equilibrium prices decrease with the search cost. Because both firms’ prices are observable, they compete to make their products prominent to attract consumers’ initial searches. Consequently, an increase in the search cost makes consumers less likely to continue to search after their first search, and this will intensify the competition for the first search, which drives the equilibrium prices down. This observation is consistent with the finding in Choi et al. (2018), which focuses on independent products. We extend this result to the case where products are correlated.

More interestingly, the model illustrates a tradeoff between complementarity and differentiation. Sharing the feature  $X$  introduces two opposing effects. It increases consumers’ incentives to inspect a product

**Figure 5.** (Color online) Comparison of Equilibrium Prices and Profits Between Correlated and Independent Products (for  $\alpha = -2$ )



and results in an expanded search region, which reflects the new consumers who would not consider any of the products in the first place if they were independent. This effect is stronger as the search cost  $c$  increases, provided that  $c$  is not too high and eliminates the complementarity effect. Intuitively, even though a higher search cost  $c$  weakens a consumer’s incentive to both search in the first stage and continue to search in the second stage, it weakens the incentive to continue to search less, because in the second stage, she will only continue if she has received positive news on  $X$  from the first search, which makes her more incentivized to overcome the search cost and continue to search in the second stage. The search boundaries,  $u_0 = \frac{10}{3}c - 2$ ,  $\bar{u} = 4c - 2$ , and  $\underline{u} = 2c - 2$  reveal this, because both  $\bar{u} - u_0 = \frac{2}{3}c$  and  $u_0 - \underline{u} = \frac{4}{3}c$  increase with  $c$ . Thus, the size of the expanded search region, as roughly measured by the difference between  $S'_{cor}$  and  $S'_{ind}$  and the difference between  $S''_{cor}$  and  $S''_{ind}$ , increases with search cost  $c$ .

However, with correlated features, products are less differentiated. A negative realization of the common attribute spills over to the correlated product, lowering the purchase likelihood for both. Consequently, both products have less market power and are faced with fiercer price competition. The effect that dominates depends on the level of the search cost. With a higher search cost, the complementarity effect dominates the competition effect, leading to higher equilibrium price and profit in the case of correlated products. However, there is a limit for this tradeoff to occur. As shown in Theorem 2, when the search cost becomes exceedingly high (i.e.,  $c \geq 1$  under the setting that we have assumed in this section), the informational complementarity effect disappears. Thus, firms with independent products enjoy higher equilibrium prices and profits, because their products are more differentiated.

The higher equilibrium prices brought about by informational complementarity imply that, by collusively manipulating the information correlation between the two products, the two firms may be able

to shift their demands from substitutes to complements. Therefore, there is a possibility for horizontal collusion via product information instead of price.

## 5. Extensions

### 5.1. Products are Negatively Correlated

Positive information from one product often implies negative aspects of the other. For example, a firm can highlight some superior features of its product using its competitors as inferior benchmarks. One product can even provide negative information about another under the same brand. For example, when searching for information on electric cars, consumers may find reviews of disadvantages of traditional gasoline cars. We expect that informational complementarity can also occur with a negative information correlation and may, in fact, be even stronger. Intuitively, if a consumer inspects one product and learns that it is not attractive because of a common attribute, then she will be drawn to the other product that is negatively correlated with the common attribute. Consequently, she may become more likely to purchase the second product. Therefore, a lower price for the first product may attract a consumer to start inspecting and eventually, purchase the second product.

To formalize this idea, consider the following setup for the consumer’s utility:

$$\begin{cases} U_1 = u_1 + X + \varepsilon_1, \\ U_2 = u_2 - X + \varepsilon_2. \end{cases} \quad (13)$$

To keep the model symmetric, we also assume that the distribution of  $X$  is symmetric around the mean, which is normalized to zero, and thus,  $\underline{X} = -\bar{X}$ . In this setup, if the consumer discovers a positive  $X$  for product 1, then she will not like  $X$  for product 2.

We can characterize the optimal search strategy similarly to Theorem 1. The proof is similar and thus, omitted. We can derive the same threshold  $\bar{u}$  following Equation (7). To derive the second threshold  $\underline{u}_i$ , notice that, after inspecting product  $i$  and discovering  $X$  and  $\varepsilon_i$ , a consumer continues to inspect

product  $j$  if and only if  $u_j - X + \varepsilon^* \geq \max\{u_i + X + \varepsilon_i, 0\}$  or equivalently,  $u_j \geq \max\{u_i + \varepsilon_i + 2X, X\} - \varepsilon^*$ , which takes the minimum value of  $\max\{u_i + \underline{\varepsilon} - 2\bar{X}, -\bar{X}\} - \varepsilon^*$  when  $\varepsilon_i = \underline{\varepsilon}$  and  $X = -\bar{X}$ . Hence, we can define  $\underline{u}_n$  as follows:

$$\underline{u}_n \equiv \max\{\bar{u} + \underline{\varepsilon} - 2\bar{X}, -\bar{X}\} - \varepsilon^*. \quad (14)$$

We can show that the complementarity effect can also arise. We provide a proof of the existence condition in the online appendix and omit the remaining proof, because it is similar to that for Theorem 2.

**Theorem 4.**

1. If  $0 < c < 2\bar{X} + E[\varepsilon] - \underline{\varepsilon}$ , then  $\bar{u} > \underline{u}_n$ , and complementarity effect arises when  $u_i \in (\underline{u}_n, \bar{u})$ :  $D_i(u_i, u_j)$  first jumps from 0 to a positive level and then, decreases with  $u_j$ . There is no complementarity for  $u_i \notin (\underline{u}_n, \bar{u})$ :  $D_i(u_i, u_j)$  always weakly decreases with  $u_j$ .
2. Otherwise, we then have that  $\bar{u} \leq \underline{u}_n$ , and there is no complementarity effect:  $D_i(u_i, u_j)$  always weakly decreases with  $u_j$ .

Notice that, by definition,  $\underline{u}_n < \underline{u}$ , and the upper bound for the search cost  $2\bar{X} + E[\varepsilon] - \underline{\varepsilon}$  is greater than that in the case of positive correlation. This implies that, compared with the main model, information complementarity is even more likely to arise under a negative correlation than under a positive correlation in the sense that a wider range of  $u_i$  and  $c$  allows for  $D_i(u_i, u_j)$  to be nonmonotonic with respect to  $u_j$ . This is consistent with our intuition above. Under the main model, any realization of the common attribute is shared by both products, and the difference between the two lies only in the idiosyncratic attributes. However, under a negative correlation, a bad realization of the common attribute after inspecting one product implies that the other product has a better outcome, providing a stronger motivation to continue to search.

To illustrate the effect, consider the two-point distributional assumption that  $X$  takes the value of either  $-\beta$  or  $\beta$  with equal probability and that  $\varepsilon_i$  equals either  $-1$  or  $1$  with equal probability. Figure 7 in the online appendix illustrates the demand of product 2 as a function of  $u_1$  and  $u_2$  under the parameter setting that  $\beta = 1$  and  $c = 0.5$ . Thus, informational complementarity arises when  $u_1$  is within the intermediate range.

**5.2. Consumers Search Under Exogenous Order**

In our main model, a consumer endogenously determines the order of products to search. In many real-world settings, however, consumers may search in an exogenously given order. For example, a car dealer may present a lower-end (or higher-end) model to a customer and induce her to inspect it first before other models. Online retailers frequently recommend products to targeted consumers, inducing them to

learn about these products first before browsing the retailer’s other products.

To model these situations, we assume that a consumer has to inspect product 1 first before inspecting product 2. Given the exogenous search order, the consumer’s decision problems in the second and last stages are exactly the same as those in the main model. Thus, the value functions  $V_2(X, \varepsilon_1, \varepsilon_2)$  and  $V_{11}(X, \varepsilon_1)$  can still be defined by Equations (2) and (3). However,  $V_{12}(X, \varepsilon_1)$  does not apply here, because the consumer always inspects product 1 first. In the first stage, she decides between the outside option and inspecting product 1.

With Equations (7) and (10), we can similarly define  $\bar{u}$  and  $\underline{u}$  in the setting with an exogenous search order. There is an additional threshold that we need to define. Suppose that  $u_2$  is very high and that  $u_1$  is very low; then, a consumer may want to inspect or purchase product 2, but she must first inspect product 1 by assumption. Here, the consumer may never purchase product 1, and the sole reason for her to inspect product 1 is to continue to inspect product 2. Formally, when  $u_1 < -\bar{X} + \underline{\varepsilon}$ , product 1 is dominated by the outside option, and therefore, the consumer will never purchase it. Thus, we can simplify  $E[V_{11}(X, \varepsilon_1)] = E[\max\{-c + E[\max\{u_2 + X + \varepsilon_2, 0\}|X], 0\}]$ . Define  $\bar{u}_e$  by the following equation:

$$E[\max\{-c + E[\max\{\bar{u}_e + X + \varepsilon_2, 0\}|X], 0\}] = c. \quad (15)$$

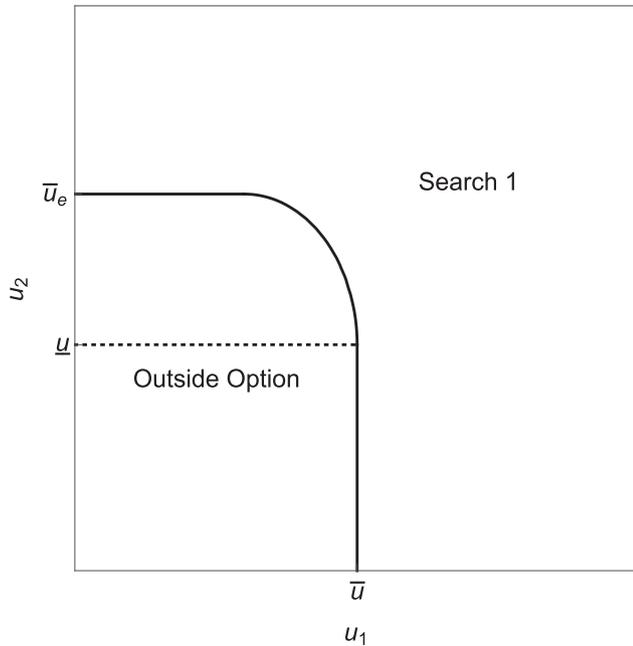
Then, by definition, we know that, when  $u_1 < -\bar{X} + \underline{\varepsilon}$ , the consumer will inspect product 1 in the first stage if and only if  $u_2 \geq \bar{u}_e$ . However, for  $u_1 \geq -\bar{X} + \underline{\varepsilon}$ , inspecting product 1 becomes even more preferable than taking the outside option. Hence, when  $u_2 \geq \bar{u}_e$ , it is optimal to inspect product 1 in the first stage. In the online appendix, we prove the following lemma.

**Lemma 1.** For any parameter setting,  $\bar{u}_e \geq \underline{u}$ .

We outline the optimal search strategy in the first stage in Figure 6. When  $u_2 \leq \underline{u}$ , the consumer will never consider product 2 and will inspect product 1 if and only if  $u_1 \geq \bar{u}$ . When  $u_2 \geq \bar{u}_e$ , the consumer will optimally inspect product 1. Last, when  $u_2 \in (\underline{u}, \bar{u}_e)$ , the consumer’s indifference curve between inspecting product 1 and taking the outside option should decrease with  $u_2$ , because intuitively, a higher ex ante utility of product 2 increases the expected gain from inspecting product 1. Based on the optimal search strategy, we can characterize the conditions for the complementarity effect to arise as follows. The proof is very similar to that of Theorem 2, and thus, it is omitted.

**Theorem 5.** The complementarity effect arises when  $u_2 \in (\underline{u}, \bar{u}_e)$ :  $D_2(u_2, u_1)$  first jumps from zero to a positive level and then, decreases with  $u_1$ . There is no

**Figure 6.** Illustration of a Consumer’s Optimal Search Strategy Under an Exogenous Search Order



complementarity for  $u_2 \notin (\underline{u}, \bar{u}_e)$ :  $D_2(u_2, u_1)$  always weakly decreases with  $u_1$ .

With an exogenous search order, the complementarity effect can arise even with independent products. In fact, Lemma 1 does not rely on the assumption that  $\text{Var}[X] > 0$ . The reason is that, in order for a consumer to purchase product 2, she has to inspect product 1 first. A lower product 1 price makes searching on product 1 more attractive, which can increase the demand for product 2. Figure 8 in the online appendix illustrates the demand functions  $D_i(u_1, u_2)$  under the assumption of two-point distributions of  $X$  and  $\varepsilon_i$ . Informational complementarity arises when  $u_2$  is in the intermediate range.

**5.3. Consumers Learn from Experience Under Repeated Purchases**

The main model focuses on the single-purchase context in which consumers make only one single purchase and acquire information before purchase. In this section, we extend the idea of informational complementarity to the repeated purchase context in which consumers can acquire information through past choices and consumptions, which has been investigated extensively in the empirical literature, but under the assumption that products are independent (e.g., Erdem and Keane 1996, Lin et al. 2015). This scenario often occurs in many markets, including consumer packaged goods, such as food and beverage, health care, and personal care products. Making one product attractive may induce consumers to try a

different yet correlated product, resulting in complementarity between the two products.

Following the standard approach to modeling repeated purchases, we assume an infinite horizon problem in which a consumer makes a purchase decision in each of the infinite stages (or purchase occasions) with the discount factor  $\delta$ . Unlike in the main model, we assume that, in each stage, the consumer can purchase either one of the two products and learn about its quality after consumption or take the outside option. Thus, whereas in the main model, the consumer faces the tradeoff between the option value and search cost, here she faces the tradeoff between exploration and exploitation. For simplicity, we assume that the consumer does not acquire information about the product quality before purchase; instead, the product information is only revealed after she makes the purchase. This assumption fits well with experience goods.

We maintain the information structure of the main model: when the consumer tries product  $i$ , she learns fully the common attribute  $X$  and the idiosyncratic attribute  $\varepsilon_i$  unique to  $i$ . Under this setup, the consumer’s purchase behavior will become steady after two stages at most.<sup>14</sup> We are thus interested in the steady-state demand  $D_i$  for product  $i$  after two stages.

The optimal learning strategy is very similar to that of the main model. Let us first derive the threshold,  $\bar{u}_r$ , for trying product  $i$  in the absence of product  $j$ . The threshold is the solution to the following Bellman equation:

$$\bar{u}_r + \frac{\delta}{1 - \delta} E[\max\{\bar{u}_r + X + \varepsilon_i, 0\}] = 0. \quad (16)$$

To derive the second threshold, beyond which the presence of product  $j$  makes trying product  $i$  more attractive, we set  $u_i = \bar{u}_r$  and search for the smallest  $u_j$  that can encourage the consumer to try product  $j$ . Similar to the argument in the main model, the smallest  $u_j$  is attained when the realization of product  $i$  provides the greatest incentive to try product  $j$ : that is, when  $(X, \varepsilon_i) = (\bar{X}, \underline{\varepsilon})$ . The threshold,  $\underline{u}_r$ , is then the solution to the following Bellman equation:

$$\underline{u}_r + \bar{X} + \frac{\delta}{1 - \delta} E[\max\{\underline{u}_r + \bar{X} + \varepsilon_j, U_0\}] = \frac{U_0}{1 - \delta}, \quad (17)$$

where the left-hand side is the option value of trying product  $j$  and the right-hand side is the value of choosing either product  $i$  or the outside option, and  $U_0 = \max\{\bar{u}_r + \bar{X} + \underline{\varepsilon}, 0\}$ . We thus derive the following relationship between the two thresholds and give the proof in the online appendix.

**Lemma 2.** For any parameter setting,  $\bar{u}_r > \underline{u}_r$ .

Lemma 2 implies an even weaker condition for the complementarity effect under the repeated purchase

problem than under the search problem. Intuitively, compared with the search problem, the opportunity to repeat purchases leads to less competition between products, because the consumer can try out multiple products before settling on one in particular. The exploration incentive strengthens the complementarity effect. The following theorem characterizes the conditions for the complementarity effect to arise. The proof is very similar to that of Theorem 2, and thus, it is omitted.

**Theorem 6.** *Complementarity effect arises when  $u_i \in (\underline{u}_r, \bar{u}_r)$ :  $D_i(u_i, u_j)$  first jumps from zero to a positive level and then, decreases with  $u_j$ . There is no complementarity for  $u_i \notin (\underline{u}_r, \bar{u}_r)$ :  $D_i(u_i, u_j)$  always weakly decreases with  $u_j$ .*

Figure 9 in the online appendix illustrates the demand functions under the assumption of two-point distributions of  $X$  and  $\varepsilon_i$ . Informational complementarity arises when  $u_2$  is in the intermediate range.

#### 5.4. Consumers Cannot Distinguish Common and Idiosyncratic Attributes

Although consumers learn the realized value of a product after searching, in some scenarios, they may not be able to discern how much the value is owing to individual attributes. For example, after a test drive, a consumer may find that the BMW electric car provides a good driving experience and will then think positively about the car. However, this could be because of the electric engine or other design elements. To capture this idea, we modify the main model and assume that, after inspecting product  $i$ , a consumer only learns the total valuation of the uncertain attributes  $y_i = X + \varepsilon_i$ . Conditional on the value of  $y_i$ , the consumer then decides whether to purchase the product, continue to inspect product  $j$ , or take the outside option. To ensure that the model is tractable and also realistic, we assume that both  $X$  and  $\varepsilon_i$  are continuously distributed without loss of generality. If the distributions are discrete, then the conclusions are heavily driven by the assumptions on the supports of the distributions. For example, if both  $X$  and  $\varepsilon_i$  follow two-point distributions with nonidentical supports, then the consumer may infer each attribute value from the total value of the two.

We can obtain a similar result to Theorem 2 following the same procedure. First, we can derive the same threshold  $\bar{u}$  as in Equation (7) based on the reduced problem that assumes the absence of product  $j$ . Second, following the same idea behind Equation (10), we can derive a similar threshold  $\underline{u}_{nd}$ . The following lemma summarizes the solution to  $\underline{u}_{nd}$  and the condition for  $\bar{u} > \underline{u}_{nd}$ . The proof is given in the online appendix.

**Lemma 3.**  *$\underline{u}_{nd}$  is the solution to  $E[\max\{\underline{u}_{nd} + y_j, 0\} | y_i = -\bar{u}] = c$ . In addition,  $\bar{u} > \underline{u}_{nd}$  if and only if  $0 < c < E[\max\{\varepsilon_j - \varepsilon_i, 0\} | y_i = -\bar{u}]$ .*

Similar to Theorem 2, we can derive the conditions for the complementarity effect to arise. The proof is very similar, and thus, it is omitted.

**Theorem 7.** *Assume that both  $X$  and  $\varepsilon$  are continuously distributed.*

1. *If  $0 < c < E[\max\{\varepsilon_j - \varepsilon_i, 0\} | y_i = -\bar{u}]$ , then  $\bar{u} > \underline{u}_{nd}$ , and complementarity effect arises when  $u_i \in (\underline{u}_{nd}, \bar{u})$ :  $D_i(u_i, u_j)$  first jumps from zero to a positive level and then, decreases with  $u_j$ . There is no complementarity for  $u_i \notin (\underline{u}_{nd}, \bar{u})$ :  $D_i(u_i, u_j)$  always weakly decreases with  $u_j$ .*

2. *Otherwise, we have that  $\bar{u} \leq \underline{u}_{nd}$ , and there is no complementarity effect:  $D_i(u_i, u_j)$  always weakly decreases with  $u_j$ .*

Again, the informational complementarity effect arises when the search cost is not too high and when the ex ante preferences are not too extreme. However, when the attributes cannot be disentangled, the conditions for the effect become stronger, implying that it is less likely to occur than in the main model where the consumer can distinguish between the common and idiosyncratic attributes. Suppose that the continuous distribution of  $\varepsilon$  has infinite support. Then,  $\underline{u} = -\infty$  in the main model, whereas  $\underline{u}_{nd}$  is finite if attributes cannot be disentangled. In addition, the condition  $c < E[\max\{\varepsilon_j - \varepsilon_i, 0\} | y_i = -\bar{u}]$  is stronger than the condition  $c < E[\varepsilon] - \underline{\varepsilon} = \infty$  in the main model.

Although the condition becomes more restricted, we can still expect it to be satisfied under regular distributional assumptions. Suppose that both  $X$  and  $\varepsilon_i$  follow zero mean normal distributions with standard deviations  $\sigma_x$  and  $\sigma_\varepsilon$ . Then,  $y_i$  follows a normal distribution with mean zero and standard deviation  $\sigma_y = \sqrt{\sigma_x^2 + \sigma_\varepsilon^2}$ . The threshold  $\bar{u}$  is the solution to the following equation:

$$\bar{u} \Phi\left(\frac{\bar{u}}{\sigma_y}\right) + \sigma_y \phi\left(\frac{\bar{u}}{\sigma_y}\right) = c, \quad (18)$$

where  $\Phi(\cdot)$  and  $\phi(\cdot)$  represent the cumulative distribution function and the probability density function, respectively, of the standard normal distribution. Conditional on  $y_i$ ,  $y_j$  follows a normal distribution with mean  $y_i \sigma_x^2 / (\sigma_x^2 + \sigma_\varepsilon^2)$  and standard deviation  $\sigma'_y = \sqrt{\sigma_x^2 \sigma_\varepsilon^2 / (\sigma_x^2 + \sigma_\varepsilon^2) + \sigma_\varepsilon^2}$ . We can then obtain  $\underline{u}_{nd}$  from the following equation:

$$\left(\underline{u}_{nd} - \frac{\sigma_x^2}{\sigma_x^2 + \sigma_\varepsilon^2} \bar{u}\right) \Phi\left(\frac{1}{\sigma'_y} \left(\underline{u}_{nd} - \frac{\sigma_x^2}{\sigma_x^2 + \sigma_\varepsilon^2} \bar{u}\right)\right) + \sigma'_y \phi\left(\frac{1}{\sigma'_y} \left(\underline{u}_{nd} - \frac{\sigma_x^2}{\sigma_x^2 + \sigma_\varepsilon^2} \bar{u}\right)\right) = c. \quad (19)$$

Although there is no closed form expression for  $\bar{u}$  and  $\underline{u}_{nd}$ , one can easily compute these values and identify the condition  $\bar{u} > \underline{u}_{nd}$  for any parameter value of  $\sigma_x$  and

$\sigma_\varepsilon$  using a simulation method based on Equations (18) and (19). For example, assuming that  $\sigma_x = \sigma_\varepsilon = 1$ , it is found that  $\bar{u} > \underline{u}_{nd}$  when  $c < E[\max\{\varepsilon_j - \varepsilon_i, 0\} | y_i = -\bar{u}] = 0.4057$ .

### 5.5. Consumers Search with More Than Two Alternatives

In this subsection, we consider a consumer's search problem among three products and an outside option, where two products share a common attribute and the third product only has an idiosyncratic attribute. Specifically, the consumer's utility of products 1 and 2 is  $U_i = u_i + X + \varepsilon_i$  for  $i = 1, 2$ , the same as in the main model. Her utility of product 3 is  $U_3 = u_3 + \eta$ , with  $\eta$  uncertain to her a priori and being revealed on search.  $\varepsilon_1$ ,  $\varepsilon_2$ ,  $X$ , and  $\eta$  are independently distributed with mean zero, and  $\varepsilon_1$  and  $\varepsilon_2$  follow the same distribution, which could be different from the distribution of  $\eta$ . The consumer follows a sequential search among the three products with the search cost  $c$  before making a purchase decision.

Obviously, our main model in Section 2 is a special case of the model considered here, with  $u_3 = -\infty$ . Therefore, when  $u_3$  is low enough, informational complementarity will arise between products 1 and 2 given a positive but not very high search cost  $c$ . It is beyond the scope of this study to fully characterize the necessary and sufficient condition for informational complementarity to arise between products 1 and 2, which is a complex problem, because a consumer may opt to inspect product 3 after inspecting product 1 and before inspecting product 2. Our objective is instead to investigate whether it is possible for informational complementarity to arise between products 2 and 3 (and similarly, between products 1 and 3), which share no common attribute. The following proposition provides a negative answer to this question, with proof in the online appendix.

**Proposition 1.** *There is no demand complementarity between products 2 and 3. The demand for product 2 always weakly decreases with  $u_3$ , and the demand for product 3 always weakly decreases with  $u_2$ .*

The proposition states that, if a product (product 3 in this case) is uncorrelated with the others, there is no demand complementarity effect between this product and the others. It demonstrates that the correlation among products is crucial to enable the informational complementarity effect when consumers search sequentially with an endogenous search order.

## 6. Conclusion

This study is motivated by the observation that many products share similar or common features, and

consumers are often uncertain about these features. We explore the interesting implications of this phenomenon. Based on a consumer sequential search model, we show that correlated uncertain information among products can lead to a demand complementary effect for substitutes. We term this effect informational complementarity, and we show that it arises when the search cost is not very high and when a consumer's ex ante utilities of the alternatives are close to the outside option. We also demonstrate that this effect is robust to a variety of decision scenarios, including negative information correlation, exogenous search order, repeated purchases, nondecomposable attributes, and more than two products.

The informational complementarity effect has important implications for pricing. We take an initial step to investigate this issue and illustrate the tradeoff between complementarity and differentiation under competition. Being correlated can naturally lead to less differentiation and intensified price competition. However, we identify the possibility that informational complementarity leaves room for firms to collectively raise prices.

Our work opens up several opportunities for additional investigation. First, we have not explored the interesting implication of how competing firms should advertise their product features in the presence of correlation. Second, in terms of product line design, the optimal level of product commonality balances demand cannibalization and informational complementarity, which is another interesting research direction. Third, our theoretical results provide testable predictions about the informational complementarity effect, and therefore, future research can test these predictions in an empirical setting.

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## Endnotes

<sup>1</sup>The index policy is known as the Gittins Index (Gittins and Jones 1974) for general multiarmed bandit problems in the statistics and operations research literature. For search problems, this is specifically known as Pandora's rule (Weitzman 1979) in the economics literature.

<sup>2</sup>Kuksov and Villas-Boas (2010), Armstrong and Zhou (2011), Ke et al. (2016), Garcia and Shelegia (2018), and Janssen and Ke (2019) all introduce some level of specific product correlations, but none of them examine the general sequential search framework and identify the complementarity effect as we do.

<sup>3</sup>To simplify the exposition, we have assumed that the consumers' search cost stays constant over time. Note that consumers get less information in the second search. We can allow the search cost for the second search to be lower than that of the first, which actually makes the effect of informational complementarity stronger.

<sup>4</sup>When a consumer is allowed to purchase a product before searching on it, the optimal search problem is very complicated. In general, it is not a multiarm bandit problem, and the index policy (i.e., Pandora's rule from Weitzman) is not guaranteed to be optimal. See Doval (2018) and Ke and Villas-Boas (2019) for discussions of this problem. Nevertheless, under the two-point distribution of  $X$  and  $\varepsilon_i$ , we can show that the informational complementarity can still arise. The details on this are available from the authors on request.

<sup>5</sup>Apart from  $X$ ,  $\varepsilon_1$ , and  $\varepsilon_2$ , the consumer's decision also depends on  $u_1$  and  $u_2$ , which are assumed to be known throughout the decision process. Therefore, we do not explicitly express the value function as depending on them.

<sup>6</sup>Here, we have assumed the tie-breaking rule that, when a consumer is indifferent between searching on product  $i$  and  $j$ , she will prefer to search on product  $i$ . We will get similar results under other tie-breaking rules.

<sup>7</sup>In the framework of Weitzman (1979), a consumer's choice between searching on one product and taking the outside option depends only on the comparison of the reservation values of this product and the outside option independent of her expected utility of another product.

<sup>8</sup>In that setting, a consumer has to inspect product 1 first before inspecting product 2. A higher expected utility of product 1 means that the consumer becomes more willing to inspect it, which makes her prefer to continue to search on product 2 rather than taking the outside option. Thus, the IIA condition for search is violated, and the demand complementarity effect could arise in that setting even without correlation between products.

<sup>9</sup>A different approach to modeling competitive pricing with consumer search is to assume that consumers do not observe prices a priori. When visiting a firm, consumers discover both the idiosyncratic attributes and the price, which in equilibrium, coincide with the consumer's expectations (e.g., Wolinsky 1986, Anderson and Renault 1999, Armstrong et al. 2009). We do not adopt this setup, because if prices are not observable, they do not influence consumers' search behavior directly, and thus, there is no informational complementarity effect.

<sup>10</sup>Most studies in the literature, therefore, focus on the setting of monopolistic competition where there is an infinite number of firms and thus, no returning demand.

<sup>11</sup>Notice that, if a consumer inspects product  $i$  first and finds that  $X = 1$  and  $\varepsilon_i = 1$ , she will never go on to inspect product  $j$ . Inspecting product  $i$  first means that  $u_i \geq u_j$ , which further implies that  $U_i = u_i + X + \varepsilon_i = u_i + 2 \geq u_j + X + \varepsilon_j$ . That is, product  $j$  is always dominated by product  $i$ , and therefore, the consumer should buy product  $i$  right away if  $U_i = u_i + X + \varepsilon_i \geq 0$ , or she should take the outside option right away.

<sup>12</sup>The plot is made in the case with  $p_1 > p_{ind}^*$ . The other case with  $p_1 \leq p_{ind}^*$  can be plotted similarly.

<sup>13</sup>If  $X = -1$ , then  $U_j < 0$  for any realizations of  $\varepsilon_j$ . This implies that the consumer will never purchase product  $j$ , and thus, she will never continue to inspect  $j$ .

<sup>14</sup>This assumption, however, is a simplification of the Bayesian learning approach commonly adopted in the dynamic learning literature (see, for example, Erdem and Keane (1996) and Lin et al. (2015)). Nevertheless, it captures the essence of the exploration versus exploitation problem and is consistent with the main model setup.

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