# Consumer Choice and Market Outcomes under Ambiguity in Product Quality

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Facing purchase choice involving ambiguity in product quality, consumers behave in a boundedly rational manner. Consumers also exhibit varying degrees of predisposition towards a product. We present a simple model of boundedly rational choice under ambiguity. The model's key feature is that it captures the interaction between predisposition and ambiguity. We build on the choice model to derive demand curves and the unique equilibrium market outcomes (regarding prices, profits, and market shares) under duopolistic competition. In equilibrium, market shares are proportional to prices. In symmetric competition, higher equilibrium prices obtain when the ambiguity in product quality is high or when the customer base is partisan. For vertically differentiated products, the strategy of a higher-quality firm to marginally reduce ambiguity depends on the ambiguity level inherent in the product–market environment. The presence of informed customers may increase the equilibrium prices and profits of both firms. An understanding of the predisposition–ambiguity interaction may improve the firm's information and brand management strategy.

*Key words*: bounded rationality, ambiguity, predisposition, hypothesis testing, multiattribute utility, information strategy, competition

## 1. Introduction

Imagine you are choosing between two resorts ($A$ and $B$) for your annual vacation on an island. Your preference for one resort over the other depends on price and quality, but quality is difficult to assess. We take "quality" as a summary measure that captures all factors *other* than price: service, amenities, proximity to ocean, and so on. A casual check of the price and quality suggests resort $B$ as the more attractive choice, but the evidence is not conclusive. Also, you find yourself favorably predisposed to resort $A$—for reasons such as prior experience, positive associations, habit, or inertia—and want to give its quality the benefit of a doubt. After some thinking, you are not convinced that the evidence about the quality of resort $B$ is sufficiently convincing to overturn your initial predisposition; hence you choose resort $A$.

Although quality is the key non-price consideration driving consumer purchase decisions (Leffler 1982), consumers often lack knowledge and encounter missing or conflicting information about

product quality. It is also difficult to evaluate the quality of a vacation resort, an attorney, a tennis instructor, a physical therapist, or a new electric car. Yet the consumer must, nonetheless, make a choice. When product quality is ambiguous—owing to the cost of processing information (Simon 1955, Stigler 1961, Sims 2003), limits on reasoning (Camerer et al. 2004, Crawford and Shum 2005), or an aversion to thinking (Ergin and Sarver 2010, Ortoleva 2013)—consumers do not compute and compare subjective expected utilities of each product before making a purchase. Instead, they behave in a *boundedly rational* way and rely on their initial preference or liking for a product (based on familiarity, positive associations, affect, prior experience, etc.) to simplify the decision process. A consumer favorably predisposed towards a product often "anchors" on this predisposition and so prefers the product absent evidence strong enough to change that preference. Examples abound: those who are already suspicious of vaccinations (because of side effects) are reluctant to vaccinate when there is ambiguity about vaccination risk (Ritov and Baron 1990); investors overweight domestic securities over foreign securities in their portfolios (French and Poterba 1991); and consumers prefer the incumbent brand over a superior new product when assessing quality is difficult (Smith and Park 1992, Muthukrishnan 1995). In addition, research on consumer behavior consistently finds that ambiguity and predisposition interact to influence consumer choice (Hoch and Ha 1986, Ha and Hoch 1989, Muthukrishnan 1995).

The first goal of this paper is to present a boundedly rational model of consumer choice that explicitly accounts for the interaction between predisposition and ambiguity. Consumer decision process follows the spirit of the *hypothesis testing* framework. A predisposition towards a certain product (strength of the null hypothesis) creates an advantage for that product over its competitor, although this advantage can be overturned by evidence (strength of sample information). Because the evidence is ambiguous, a competing product will not be chosen unless it either demonstrates sufficiently higher quality or offers a sufficiently lower price (or some combination of these advantages). This observation leads to an expression for the price premium that a consumer is willing to pay for a product; that expression incorporates both the quality difference between the two products and the interaction between ambiguity and predisposition. The interaction term (ambiguity×predisposition) reflects the threshold that the competing product must meet to overcome a consumer's initial favorable predisposition towards the original product.

We then present our multi-attribute utility model of consumer choice, in which a product's valuation depends on the following attributes: product price, quality, consumer predisposition, and ambiguity present in the product–market environment. Behavioral assumptions are used to derive the functional form of this multi-attribute utility model. In the special case of two products, the price premium obtained from the model coincides with that obtained from the hypothesis testing framework.

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Our consumer choice model is a boundedly rational alternative to the Bayesian updating model, which requires knowledge about prior beliefs, assessment of likelihood functions, and coherent use of sample information to arrive at posterior beliefs that are then used to compute expected utility. Camerer (1998) observes that humans do not actually employ Bayesian updating and calls for a boundedly rational model "that is formal and analytically useful, but not too complicated." Simon (1990) advocates for devising models that deal with uncertainty without assuming knowledge of probabilities. In our multi-attribute utility model, a consumer resorts to a simple decision process in which—much as in risk–value models (Sarin and Weber 1993)—price, quality, ambiguity, and predisposition are viewed as attributes. If quality is not ambiguous or if the consumer is not predisposed towards either product, then his behavior is consistent with expected utility maximization.

The second goal of this paper is to investigate the equilibrium prices, profits, and market shares that each firm would obtain in a duopolistic setting. Our competitive dynamics is between two vertically differentiated products (firms). Integrating the price premiums derived from our choice model across consumers with varying predisposition levels, we derive a demand curve that depends on the interaction between degree of ambiguity and predisposition. When there are two firms competing to maximize their respective profits, each will attempt to attract the other's customers by undercutting its prices. We show that unique equilibrium prices emerge as each firm balances the profits gained from new customers with the profits lost from existing ones. In equilibrium, market shares are proportional to prices.

In product–market environments there is often some ambiguity about the quality difference between firms; moreover, consumers typically differ in the degree of their respective predispositions towards a firm. We show that when ambiguity is high or the customer base is more partisan, price competition between firms diminishes and higher prices result. This outcome arises because the interaction of predisposition and ambiguity creates decision inertia for consumers, and the demand for each firm becomes "stickier" and less responsive to price changes. Note that greater ambiguity also protects the lower-quality firm from losing market share to a higher-quality competitor. It is well known that, in vertically differentiated markets, the higher-quality firm captures the quality-conscious consumers while the lower-quality firm settles for serving cost-conscious consumers. We show that even when the price–quality trade-off is identical for all consumers, the lower-quality firm in vertical competition will capture a segment of consumers in the presence of ambiguity and predisposition.

The interaction of predisposition and ambiguity yields some managerial insights. Because the extent of ambiguity about product quality depends on the particular product–market environment, firms cannot choose its level unilaterally; however, they can take actions (e.g., providing more information) to reduce it at least marginally. We find that whether or not a new entrant

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with a higher-quality product (but facing an incumbent to which the consumer base is favorably predisposed) should marginally reduce ambiguity depends on the ambiguity level of the focal product–market environment. The reason is that any gain in market share from reducing ambiguity may be offset by the lower price resulting from greater price competition. For products with simple and less ambiguous quality measures (e.g., the life expectancy of batteries or light bulbs), the higher-quality firm will benefit from any reduction in that ambiguity. For complex products with non-overlapping attributes for which quality comparisons are inherently more difficult (e.g., vacation resorts), the higher-quality firm may find it profitable to tolerate ambiguity. Marketing efforts could then be devoted to increasing predisposition rather than to reducing ambiguity.

In some product–market environments, a segment of consumers may be loyal to one brand and not consider the competing brand. We derive equilibrium prices in the presence of loyal customers. The loyal customers tend to nudge the equilibrium prices and profits higher. We also examine how consumers who are fully informed affect market outcomes. In some product–market environments, a segment of consumers may be fully informed about quality differences (as when medical professionals have specialized knowledge about generic versus branded drugs). A surprising result is that, within a certain range, increases in the proportion of fully informed consumers increases the equilibrium profits of both firms. So under vertical competition, even the lower-quality firm benefits when more consumers know of its inferior quality. This is because the fully informed consumers will purchase from the higher-quality firm, leaving a smaller segment of consumers for which to compete. Because the higher-quality firm has more to lose by undercutting prices, it is less willing to do so; that reluctance enables the lower-quality firm to maintain its market share.

In the next section, we briefly review the relevant literature. In section 3 we present our consumer choice model, which captures the interaction of predisposition and ambiguity in product choice; this model is then used to derive price premiums and the demand curve. Section 4 examines the implications of ambiguity for equilibrium market outcomes, and section 5 explores the effect of loyal consumers and fully informed consumers on the demand curve and on market outcomes. In section 6, we discuss our managerial insights and provide summary and conclusion.

## 2. Literature Review

A substantial body of research on consumer behavior supports the notion that ambiguity in product quality moderates the effect of predisposition on a consumer's choice. The notion of *ambiguity*, though context specific, refers to the difficulty in assessing or comparing quality because of missing or conflicting information. We use the term *predisposition* with reference to an initial preference or liking for a product that springs from prior experience, positive association, and/or familiarity. The interaction of these two primitives, ambiguity and predisposition, results in an inertia that

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**Table 1**     Interaction between predisposition and ambiguity.

NEW YORK TIMES/CBS NEWS POLL

| Question | Reagan/ Bush | Mondale/ Ferraro | Undecided | Total |
|---|---|---|---|---|
| Who won Sunday night's debate? | | | | |
| Reagan | 26% | 1% | 14% | 17% |
| Mondale | 50% | 93% | 68% | 66% |
| No opinion | 24% | 6% | 18% | 17% |
| Who won Thursday night's debate? | | | | |
| Bush | 78% | 5% | 22% | 47% |
| Ferraro | 4% | 73% | 19% | 31% |
| No opinion | 18% | 22% | 59% | 22% |

*Candidate preferences* spans the columns Reagan/Bush, Mondale/Ferraro, Undecided, Total.

favors the status quo or the more familiar product. Table 1, adapted from Hoch and Ha (1986), is a classic illustration of how the interaction between predisposition and ambiguity affects judgment. After the Bush–Ferraro vice-presidential debate, a clear majority of respondents judged that the candidate toward whom they were predisposed had won. That the debate's outcome was ambiguous is evidenced by the response of neutral (i.e., not already predisposed; in the table, "Undecided") observers, of whom 59% had no opinion about which candidate had won the debate. The Reagan–Mondale presidential debate outcome was much less ambiguous: 68% of the neutral respondents felt that Mondale had won. In fact, half of the respondents who were predisposed to Reagan overcame that predisposition in concluding that Mondale had won the debate.

In the same spirit, Ha and Hoch (1989) show that consumers rely more on their predispositions when choosing a color television when there are more product attributes to be compared (i.e., when there is a higher degree of ambiguity). In purchase decisions involving a new product, Smith and Park (1992) find that consumers rely more on the brand (predisposition) in product categories where assessing quality is difficult (high ambiguity) than in categories where assessing quality is easy (low ambiguity). In examining the market outcome between an incumbent—the consumer's current brand toward which she is favorably predisposed—and a new entrant offering a superior product, Muthukrishnan (1995) finds that greater ambiguity advantages the incumbent. Muthukrishnan and Kardes (2001) also report that ambiguity leads consumers to bond more with the incumbent brand by focusing on its positive attributes. Zhang and Markman (1998) show that a new entrant with a higher-quality product can exceed the incumbent's market share only if the features of their respective products are easily comparable, or *less* ambiguous. Mehta et al. (2008) demonstrate that consumer purchases of liquid detergents are more affected by advertising when the competing products are not clearly differentiated, so that their respective quality is *more*

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ambiguous. Ackerberg (2001) finds that, for a newly introduced product (Yoplait 150), advertising has a significant effect on inexperienced consumers. Effectiveness of advertising declines as number of previous purchases increase; presumably because ambiguity diminishes with experience. Similar results have been established in the setting of online commerce. The impact of brands is significantly stronger in online markets than in offline markets (Danaher et al. 2003), and reducing ambiguity reduces the importance of brands (Kim and Krishnan 2015, Kostyra et al. 2015).

The preference for a familiar option when outcomes are ambiguous seems to be rooted in the human psyche (Kahneman 2011) and is reported in various studies of decision processes, including anchoring and adjustment (Kahneman 2003), conscious versus unconscious decision processes (Loewenstein 2001), and hypothesis generation versus decision analysis (Gettys and Fisher 1979). Evidence of status quo bias (Samuelson and Zeckhauser 1988), of confirmation bias whereby individuals interpret new information to fit their existing belief (Bacon 1620/1939, Klayman and Ha 1987, Klayman 1995, Nickerson 1998), of pre-decisional information distortion (Bond et al. 2007), of the psychological burden associated with switching (Klemperer 1995), and of a marked preference for the default option (Thaler and Benartzi 2004) is all strongly indicative of the role played by decision inertia in human decision making.

The consumer choice model used in this paper captures the strength of decision inertia and how it is influenced by the level of ambiguity. Taking an approach that is different but similar in spirit, Tversky and Koehler (1994) develop "support theory" to explain why individuals assign higher subjective probabilities to events that confirm their original hypotheses. In the *subjective* expected utility model (Savage 1954), the consumer starts out with a prior, collects information, updates the prior, and then chooses the option with the highest subjective expected utility. Our predictions will match those derived from the subjective utility model in either of two cases: when no ambiguity exists about the product's quality; or when the consumer is neutral—that is, has no particular predisposition for either product.

Our consumer choice model builds on a tradition in marketing science of modeling consumers as *boundedly rational.* For example, Shugan (1980) describes explicitly modeling a "confusion index" to measure the cost of thinking, and Munier et al. (1999) remark that "bounded rationality modeling is becoming an important part of economic analysis as well as of marketing science." Several recent studies examine how consumers' bounded rationality affects market outcomes. Chen et al. (2010) study the consequences for firm decisions when consumers have limited memory; Lin et al. (2014), in their study of how forward-looking experiential learning influences market outcomes, assume that consumers employ a cognitively simple "index heuristic"; and Huang and Yu (2014) examine the efficacy of "probabilistic selling" when consumers use anecdotal reasoning. Our boundedly rational model of consumer choice is an alternative to Bayesian updating models, which yield

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far more complex descriptions of consumer choice (Mehta et al. 2008) and whose approach of updating prior beliefs—based on the assessment of likelihood functions and the coherent use of sample information—does not capture the decision process of a typical consumer (Camerer 1998). We present a simple model of bounded rationality and then examine how market outcomes are affected by the interaction between ambiguity and predisposition.

Our setting, in which firms face consumers for whom product quality is ambiguous, has been widely studied in the marketing literature. One stream of literature focuses on the firm's efforts to signal quality. The key to signaling is that the higher-quality firm is willing to take actions that the competing firm of lower quality deems not to be worthwhile. Examples of these actions include: uninformative advertising, or "money burning" (Nelson 1974, Milgrom and Roberts 1986); pricing (Gerstner 1985); "umbrella" branding (Wernerfelt 1988); offering a money-back guarantee (Moorthy and Srinivasan 1995); sales assistance and sales techniques (Wernerfelt 1994, Bhardwaj et al. 2008); and revealing or concealing certain attribute information (Kuksov and Lin 2010, Mayzlin and Shin 2011). For a comprehensive review of signal categories, see Kirmani and Rao (2000). Our research complements the signaling literature and shows that, when consumers are boundedly rational, the success of a higher-quality firm's information strategy (i.e., of marginally reducing ambiguity about its superior product quality) depends on the ambiguity level already present in the focal product–market environment. More specifically, the higher-quality firm will further reduce a low level of ambiguity but may tolerate a high level.

Another related stream of literature examines how firms should convey information on product attributes to consumers. The aim is to reduce the consumer's ambiguity about whether a product fits his preference, a concern of some importance in a horizontally differentiated market. Grossman and Shapiro (1984) employ spatial differentiation models to represent heterogeneity in consumer preferences, and they show that informative advertising benefits consumers by improving their product match. Soberman (2004) notes that informative advertising reduces product differentiation and intensifies interfirm price competition. Several marketing studies focus on firm-level decisions about how to communicate product information in the presence of third-party information (Chen and Xie 2005), advertisements in Internet chat rooms (Mayzlin 2006), consumer reviews (Chen and Xie 2008), word-of-mouth information (Jing 2011), or negative (or outlier) reviews (Sun 2012). Taking a more micro approach, Branco et al. (2012) examine the consumer's information-gathering process; these authors establish that providing more information can benefit less well-known brands but may harm more established brands. This stream of research suggests that an information strategy to reduce consumer ambiguity about product fit can have significant effects—either positive or negative—on market outcomes. We complement that literature by examining how information

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strategy affects ambiguity about product quality, a dynamic that applies in all vertically differentiated markets. In short: ambiguity about product quality interacts with consumer predispositions to determine the ultimate prices, profits, and market shares of the competing firms.

Our concept of predisposition includes brand loyalty, which has been extensively researched in the field of marketing. Aaker (2009) argues that higher brand equity (a broader concept than brand loyalty) allows for higher margins through premium pricing and reduced promotions, whereas a product with lower brand equity needs to offer price discounts and stronger warranties—and must also invest more in promotions. Brand loyalty is often modeled "as the price differential needed to make consumers who prefer that brand to switch to some competing brand" (Raju et al. 1990); it is a strong form of preference applicable to *horizontally* differentiated products. In extreme cases, this predisposition of loyal customers is such that they will not switch brands regardless of the difference in price. For example, Colombo and Morrison (1989) define brand loyalty as the proportion of that brand's customers who are "intrinsically" loyal. Deighton et al. (1994) find a large inertial effect for ketchup and detergents, as consumers are likely to buy the same brand purchased on the previous shopping occasion. In our framework, predisposition towards a brand/product/service is not binary; the *extent* of predisposition matters. Thus a predisposition is not so much "black or white" as akin to "different shades of gray". Our concept of predisposition applies also to *vertically* differentiated product markets.

Some researchers have examined how brand loyalty affects the demand curve's sensitivity to price. Krishnamurthi and Raj (1991) find that loyal customers are less price sensitive in their product choices, and Bayus (1992) reports similar results for consumer brand loyalty in home appliances. Similarly, Agrawal (1996: 86) states that "consumers ... with stronger loyalty require a large price differential before they will switch away from their favorite brand." Park and Srinivasan (1994) present a metric for estimating the price premium that consumers are willing to pay for brand loyalty. We agree with these approaches but offer the caveat that ambiguity about product quality *accentuates* the effect of predisposition on consumers' willingness to pay. That is, the price premium depends on an interaction between strength of predisposition and degree of ambiguity.

Finally, the competitive setting we analyze is related to a range of studies that examine the impact of brand loyalty on competitive pricing and promotional strategies (e.g., Rao 1986, Narasimhan 1988, Raju et al. 1990, Wernerfelt 1991, Iyer et al. 2005, Baye and Morgan 2009). These studies assume that brand loyalty can be represented by an exogenously specified price premium. In our model, the price premium that a consumer is willing to pay depends on both predisposition and ambiguity, from which the demand curve and equilibrium market outcomes are derived. Thus, our paper complements these studies by explicitly modeling the price premium's dependence on the ambiguity level. Some studies model the factors that firms can control to influence brand

loyalty. For example, Villas-Boas (2004) assumes that brand loyalty can be developed by reducing uncertainty about fit; Chen et al. (2009) assume that firms can launch persuasive advertising to alter consumers' preferences. Unlike these studies, we assume that predisposition levels are exogenous because of our interest in the interaction between ambiguity and predisposition and in how equilibrium market outcomes are affected by that interaction.

## 3. Consumer Choice Model

In this section, we present a boundedly rational model of consumer choice under ambiguity. Ambiguity is generally caused by epistemic or aleatory sources. The former type of ambiguity arises when consumers lack knowledge and encounter missing or conflicting information about the quality of a product or service; the latter arises because of the inherent uncertainty in outcomes.[1] In reality, both sources of ambiguity are present at the same time, which complicates the assessment of quality. Consumers may experience considerable ambiguity about the relative health benefits of two types of exercise programs, not only because they lack knowledge and are presented with conflicting information but also because it is difficult to assess ex ante the likelihood of all possible health outcomes. We shall use the term *ambiguity* to reflect both epistemic and aleatory uncertainty about quality.[2]

When there is ambiguity, the consumer behaves in a *boundedly rational* manner and relies on her initial preference or liking for a product to simplify the decision process. Consumers have varying degrees of predispositions. A consumer who is favorably predisposed towards a product often anchors on that predisposition and prefers the product unless there is sufficiently strong contrary evidence. Ambiguity and predisposition are the two primitives in our paper that influence individual behavior and concomitant market outcomes. To make the interaction between these two primitives precise, we next use the hypothesis-testing framework as an illustrative example for a two-product setting.

**An intuitive building-block: Hypothesis testing**

Hypothesis testing is consistent with many decision heuristics that individuals actually follow when facing ambiguity; here we show that it is an intuitive model of bounded rational choice under

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[1] In Ellsberg's (1961) paradox, noted decades earlier by Keynes (1921), ambiguity is described as a bet involving an unknown composition of red and black balls (unknown probability distribution)—in contrast to risk, which is described as a bet involving a known composition of red and black balls (known probability distribution).

[2] Keynes (1921) was perhaps the first to argue that probabilistic reasoning breaks down when the "weight of evidence" is low. Knight (1921) argued that entrepreneurs earned economic rents from bearing epistemic uncertainty. Savage (1954) admitted that his subjective expected utility theory does not account well for cases in which one is "unsure" about the relevant probabilities. Ellsberg (1961) designed some clever experiments to show that people do *not* follow the axioms of subjective expected utility when presented with ambiguous information. Both Keynes and Ellsberg emphasized that individuals behave differently depending on whether probabilities are known or unknown.

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ambiguity. Quality may be multi-dimensional (i.e., have multiple attributes), as in Houthakker (1952). Although one could use a fairly general measure of quality (e.g., an index based on multiple dimensions), for the sake of clarity it will be useful here to focus on a simple product (batteries) with a precise measure of quality (hours of expected battery life).

Consider a consumer who faces the choice between two products, $A$ and $B$. For a given product $i \in \{A, B\}$ there exists a true quality $\mu_i$, which we take to represent each product's inherent quality. The consumer prefers higher-quality products in general, but the true qualities $\mu_i$ of $A$ and $B$ are unknown and hence ambiguous. Under our hypothesis-testing framework, the consumer first adopts the null hypothesis that the product to which he is most favorably predisposed is of superior quality. So if that is product $A$, then this hypothesis is

$$H_0 : \mu_A \geq \mu_B, \qquad H_a : \mu_A < \mu_B$$

The strength of a predisposition is measured by the significance level $\alpha$, which is the conditional probability of rejecting the null when, in fact, it is true. A strongly favorable predisposition implies a low $\alpha$ and therefore greater consumer reluctance to overturn the null hypothesis.

Then, for each product $A$ and $B$, the consumer observes respective amounts $n_A$ and $n_B$ of random sample information (e.g., consumer reviews, word of mouth)[3] before assessing the sample mean quality $q_A$ and $q_B$ and estimating the sample variances $s_A^2$ and $s_B^2$. The probability distribution of the sample mean is a student's t-distribution, which is approximated by a normal distribution with mean $\mu_i$ and variance $s_i^2/n_i$ for a large enough sample size ($n_i > 60$).

Finally, the consumer will reject the null hypothesis—and instead choose product $B$—if and only if $q_A$ is, beyond any reasonable doubt, sufficiently less than $q_B$. That is,

$$P(x < q_A - q_B) < \alpha \iff \Phi\left(\frac{q_A - q_B}{\sqrt{s_A^2/n_A + s_B^2/n_B}}\right) < \alpha \iff q_A - q_B < z_\alpha \sqrt{s_A^2/n_A + s_B^2/n_B}; \quad (1)$$

here $\Phi(\cdot)$ denotes the cumulative distribution function of a standard normal distribution and $z_\alpha$ is such that $\Phi(z_\alpha) = \alpha$. In a number of studies (e.g., Sun 2012) it is shown that average rating (valence), volume, and variance of reviews affect consumer choice and sales. Expression (1) shows how these factors interact to determine consumer choice.

The null hypothesis, as captured by the $z_\alpha$ term, plays a critical role in this decision. For the consumer with a favorable predisposition towards (i.e., null hypothesis favoring) product $A$, the term $z_\alpha$ is *negative* and so the consumer might choose the product even if $q_A < q_B$. Conversely, for the consumer with an unfavorable predisposition towards $A$ (i.e., $H_0 : \mu_B \geq \mu_A$, $H_a : \mu_B < \mu_A$), $z_\alpha$ is *positive* and so the consumer might not buy product $A$ even if $q_A > q_B$. A crucial role is also

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[3] We assume that samples are drawn independently from normal distribution for this illustrative example.

played by the $\sqrt{s_A^2/n_A + s_B^2/n_B}$ term, or the standard error of the difference in sample means. The greater this term, the more doubtful (ambiguous) becomes sample information about product quality—and the more effect predispositions have on how that information is interpreted.    □

The hypothesis testing clearly illustrates the interaction between the null hypothesis and sample information in the consumer decisions process. These two primitives (null hypothesis and sample information) are specific to hypothesis testing, but can be interpreted more broadly as predisposition and ambiguity, which we define formally next.

DEFINITION 1. *Predisposition* $\Omega$ is a preference for a product that may be based on prior experience, familiarity, positive association, or a combination of these factors.

DEFINITION 2. *Ambiguity* $\xi$ is the difficulty in assessing product quality that may arise because of missing information about product quality, conflicting or inconsistent information (product reviews, consumer opinions, and ratings), lack of knowledge, or inherent uncertainty.

Adopting these general interpretations for predisposition $\Omega$ and ambiguity level $\xi$, the key aspect of expression (1) can be generalized to this: overturning an initially favorable predisposition towards product $A$ requires the competing product $B$ to offer a quality advantage that *exceeds* $\Omega \cdot \xi$.

Without loss of generality, we adopt the convention that $\Omega < 0$, $\Omega = 0$, and $\Omega > 0$ signify (respectively) a favorable predisposition toward product $A$, a neutral predisposition, and a favorable predisposition toward product $B$; here higher $|\Omega|$ indicates a stronger predisposition. We also assume that all consumers are exposed to the same level of ambiguity $\xi$ but differ in their predisposition $\Omega$. (We explore the effect of heterogeneous $\xi$ in section 5.2.)

### 3.1. Price Premium

We now examine the effects of ambiguity and predisposition on the price premium that consumers are willing to pay. Suppose that a consumer is willing to pay a single monetary unit ($) for a unit of quality. Although a product's quality is uncertain, we assume that its price (including any discounts, rebates, or warranties) is always known. A consumer who is predisposed towards product $A$ will purchase product $B$ if and only if

$$q_A - p_A < q_B - p_B + \Omega\xi \iff p_A - p_B > (q_A - q_B) - \Omega\xi.$$

The right-hand side (RHS) of the second inequality captures the maximum price premium a consumer is willing to pay for product $A$ relative to product $B$. Our first proposition formalizes the price premium's fundamental equation, separating it into a rational component (determined by the average difference in quality) and a boundedly rational component (determined by the predisposition–ambiguity interaction). All proofs are given in Appendix B.

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PROPOSITION 1 **(Effect of Predisposition and Ambiguity on the Price Premium)**.

*For products towards which the consumer is favorably predisposed, the price premium increases with the ambiguity about product quality. Formally,*

$$\underbrace{\text{Price premium}}_{p_A - p_B} = \underbrace{\text{Quality difference}}_{q_A - q_B} - \Big( \underbrace{\text{Predisposition}}_{\Omega} \times \underbrace{\text{Ambiguity}}_{\xi} \Big). \tag{2}$$

The price premium depends on the premium due to the difference in quality $(q_A - q_B)$ and also on the predisposition $\times$ ambiguity interaction $(\Omega \cdot \xi)$, which represents the "slack" quality or benefit of a doubt that the consumer will give to product $A$ when quality is ambiguous. As a simple example of (2), suppose that $q_A - q_B = 0.25$ and assume a predisposition towards $A$ of 1 unit and an ambiguity level of $+0.5$ unit. In this case, product $A$ merits (or "deserves") a price premium of 25 cents based solely on its superior quality. However, product $B$ must be discounted *more* than 75 cents in order to attract consumers when evidence about quality is ambiguous. Equation (2) reflects the price premium for superior quality and an additional premium for greater trust in the product's reliability. The price premium for this trust component is higher when quality is ambiguous. Whereas traditional demand models focus on the heterogeneity of consumers' quality preferences (first term on the RHS of Equation (4)), we focus instead on the second (multiplicative) term's heterogeneity, which reflects the bounded rationality of consumers.

Figure 1 plots the price premium that a consumer is willing to pay for product $A$, when its quality is equal to that of product $B$, for varying levels of ambiguity. (Similar curves are obtained when their levels of quality are not the same $(q_A \neq q_B)$.) A key feature of the multiplicative term is sign dependence: the price premium *increases* with an increase in ambiguity if predisposition is favorable. In contrast, the price premium *decreases* with an increase in ambiguity if predisposition in unfavorable (left panel in Figure 1).

In Figure 1 (right panel), $\Omega > 0$ reflects the consumer's favorable predisposition towards product $B$ and so the curves for $\Omega > 0$ are mirror images of those for $\Omega < 0$. Observe that, even though $q_A = q_B$, a consumer favorably predisposed to product $A$ is willing to pay extra for it. Because the price premium is correlated with ambiguity, increased ambiguity about product quality increases a consumer's "benefit of a doubt"—in other words, increased ambiguity translates into a higher seller's premium.

Grabowski and Vernon (1992) find that, for retail over-the-counter (OTC) drugs, consumers continue to pay higher prices for the original drugs over their generic counterparts. Preference for the original brand (due to familiarity, prior experience, name recognition, etc.) and high ambiguity about the quality difference between original and generic drugs interact to yield a significant price premium for the original brand. In contrast, for products sold to hospitals (injectables)—for which

**Figure 1      Price premiums determined by sign-dependent interaction between predisposition and ambiguity.**
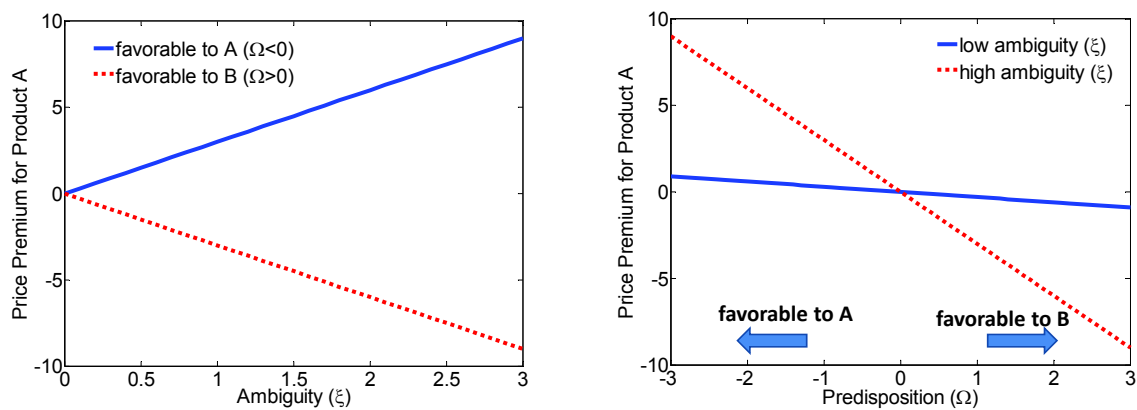


*Note.* These graphs plot the price premium that consumers are willing to pay for product $A$, as a function of their ambiguity $\xi$ and predisposition $\Omega$, when considering products of the same quality ($q_A = q_B$). A consumer who is predisposed to favor product $A$ (i.e., $\Omega < 0$) is willing to buy it at a premium despite the lack of any demonstrated superiority—a premium that increases with the level of ambiguity.

the degree of ambiguity about quality differences is low—the price premium commanded by the original brand is also low.

Consumers do not prefer higher ambiguity because no one prefers to pay a higher price premium. From the firm's perspective, however, the possibility of higher premiums is an incentive to maintain or increase ambiguity levels.

## 3.2.   Multi-attribute Utility Model

In marketing science, it is common to use a multi-attribute utility model to capture a consumer's preference. We now show that a multiattribute utility model is consistent with the result in Proposition 1. For the special case of two products, our multi-attribute utility model coincides with the hypothesis testing framework.

Suppose that a consumer's preferences among different products or services are governed by price, $p$; quality, $q$; predisposition, $\Omega$; and ambiguity, $\xi$. Note that $\Omega$ is the predisposition specific to each consumer whereas the ambiguity $\xi$ is an inherent characteristic of the product–market environment. Consider, for example, resistance to hacking—a quality attribute relevant when choosing a cell-phone platform (iPhone vs. Android) and about which there is typically mixed evidence from experts, consumer reviews, and the manufacturers themselves; hence ambiguity $\xi$ in this environment is inherently high. In settings that feature simple measures of quality (e.g., battery life), ambiguity $\xi$ is inherently low.[4]

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[4] We employ a common ambiguity measure for multiple products, not a dyadic measure. First, a common ambiguity measure is more relevant to our setting, and second, it has been used in marketing studies. For example, Hoch and Ha (1986) use a common ambiguity measure in an evaluation of the quality of six different brands of polo shirts based on interjudge reliability in their judgement of product quality. They find that quality for polo shirts is more ambiguous (low interjudge reliability) compared to the quality for toilet papers (high interjudge reliability).

Both predisposition and ambiguity could be measured using appropriately constructed and validated psychological scales. Thus a multi-attribute outcome $(p, q, \Omega, \xi)$ designates a product for which the price is $p$, quality is $q$, predisposition is $\Omega$, and ambiguity (about quality) is $\xi$. A consumer's preferences can then be represented by a utility function: $v(p, q, \Omega, \xi)$.

We define consumers by way of the three behavioral assumptions stated next. A key feature of our model is that, when a consumer is neutrally predisposed and/or product quality is unambiguous, the price premium depends only on the difference in quality. So in that case the consumer behaves simply as a maximizer of expected utility.

ASSUMPTION 1 (**Difference Independence**). *The preference difference between two products that differ in price and quality does not depend on the fixed level of predisposition and ambiguity.*

ASSUMPTION 2 (**Linearity**). *The component utilities for levels of predisposition and ambiguity are linear.*

ASSUMPTION 3 (**Zero Condition**). (a) *For a neutral consumer, $\Omega = 0$, preference depends only on price and quality.* (b) *For a fully informed consumer, $\xi = 0$, preference depends only on price and quality.*

These assumptions lead to a multi-attribute utility model of the following form.

THEOREM 1 (**Multi-attribute Utility Model**). *Under Assumptions 1–3,*

$$v(p, q, \Omega, \xi) = v_1(p, q) + \Omega\xi.$$

We remark that Assumption 2 can be weakened to permit nonlinear utilities for $\Omega$ and $\xi$. In that case, the combination of Assumptions 1 and 3 and an invariance requirement yields

$$v(p, q, \Omega, \xi) = v_1(p, q) + f_1(\Omega)f_2(\xi),$$

where $f_1(0) = 0$ and $f_2(0) = 0$.

Suppose $v_1(p, q) = \lambda q - p$, where $\lambda$ reflects the trade-off between price and quality. To be consistent with our convention, we set $\Omega < 0$ for a favorable predisposition and $\Omega > 0$ for an unfavorable predisposition. Then

$$v(p, q, \Omega, \xi) = \lambda q - p - \Omega\xi.$$

Now suppose that product $A$ and product $B$ are represented, respectively, by $(p_A, q_A, \Omega_A, \xi)$ and $(p_B, q_B, \Omega_B, \xi)$. Set the price–quality trade-off $\lambda = 1$ (e.g., battery life in hours in equivalent dollars). Then a consumer that subscribes to our multi-attribute utility model will purchase $A$ if

$$q_A - p_A - \Omega_A\xi > q_B - p_B - \Omega_B\xi \iff p_A - p_B < (q_A - q_B) - (\Omega_A - \Omega_B)\xi. \tag{3}$$

This expression is equivalent to the price premium expression (Equation 2) in Proposition 1 by substituting $(\Omega_A - \Omega_B)$ for $\Omega$.

An important feature of our multi-attribute utility model is sign dependence: the incremental price premium (beyond quality difference) *increases* with an increase in ambiguity if predisposition is favorable. In contrast (see Figure 1), the incremental price premium *decreases* with an increase in ambiguity if predisposition in unfavorable. While sign-dependent effects are observed in various marketing contexts, e.g. how consumers value a copycat brand depends on the context and uncertainty (Van Horen and Pieters 2013), we are unaware of any multi-attribute utility model that formally characterizes it.

We remark that, even though Equation (3) assumes constant price–quality trade-offs across the consumer population, the findings reported hold under a more general form of utility. For example, the multi-attribute utility model is generalizeable to include heterogeneous preferences $\lambda$ for quality. A consumer $i$ with $\lambda_i$ will choose product $A$ over $B$ if

$$\lambda_i q_A - p_A - \Omega_A \xi > \lambda_i q_B - p_B - \Omega_B \xi \iff p_A - p_B < \lambda_i (q_A - q_B) - (\Omega_A - \Omega_B)\xi.$$

Appendix A presents results for the demand curve and for equilibrium market outcomes when price premiums are affected not only by the interaction of predisposition and ambiguity but also by the heterogenous importance of quality for members of the consumer population.

The multi-attribute utility model is generalizable to the $n$-product case as well. Given $n$ products, $(p_1, q_1, \Omega_1, \xi) \ldots (p_n, q_n, \Omega_n, \xi)$, a consumer will purchase product $j$ only if

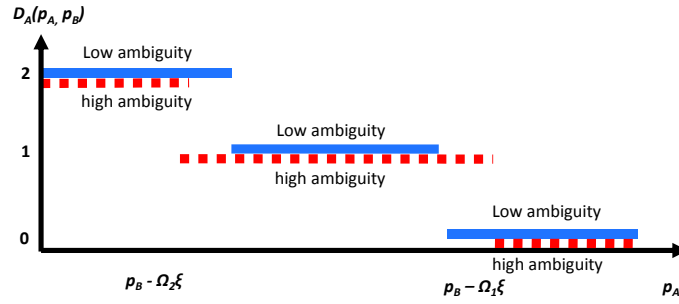$$q_j - p_j - \Omega_j \xi \geq \max_{k \neq j}\{q_k - p_k - \Omega_k \xi\}.$$

We focus on the duopoly setting. We refer the readers to the online Appendix on how the analysis can be extended when there are more than two products.

### 3.3. Demand Curve

We now derive the demand curve, which depends on heterogeneous predispositions, and examine the role of ambiguity. To illustrate the construction of a demand curve, we start by presenting a simple example that involves two customers.

EXAMPLE 1. Customer 1 is favorably predisposed towards product $A$ ($\Omega_1 < 0$) while customer 2 is favorably predisposed towards product $B$ ($\Omega_2 > 0$). The demand for product $A$ will take the value 0, 1, or 2; demand for product $B$ is simply $2 - (\text{demand for } A)$. Then

$$D_A(p_A, p_B) = \begin{cases} 0 & \text{if } p_B < p_A - (q_A - q_B) + \Omega_1 \xi, \\ 1 & \text{if } p_B + (q_A - q_B) - \Omega_2 \xi \leq p_A \leq p_B + (q_A - q_B) - \Omega_1 \xi, \\ 2 & \text{if } p_A < p_B + (q_A - q_B) - \Omega_2 \xi. \end{cases}$$

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**Figure 2** **Demand curves with two customers.**



*Note.* For higher levels of ambiguity $\xi$, demand is less responsive to price changes (i.e., is stickier).

On the one hand, if the price charged by firm $B$ $(p_B)$ is low enough to attract customer 1 (who is predisposed to $A$ and so gives it the benefit of a doubt in the amount $\Omega_1\xi$), then that customer will switch to firm $B$ and leave firm $A$ with zero demand. On the other hand, if the price charged by firm $A$ $(p_A)$ is low enough to attract customer 2 (who is predisposed to $B$ and so gives it the benefit of a doubt in the amount $\Omega_2\xi$), then both customers will buy from firm $A$. In the intermediate range of prices, customer 1 buys product $A$ and customer 2 buys product $B$.

Figure 2 shows the demand curve for product $A$ when $q_A = q_B$. When product quality is highly ambiguous, consumer inertia becomes stronger owing to the consequent greater benefit of doubt; hence customer 1 (resp. 2) stays with firm $A$ (resp. $B$) for a wider band of prices than when product quality is less uncertain. This dynamic is consistent with the one described by Erdem et al. (2002), who show that the existence of higher predisposition levels (brand credibility) reduces the price sensitivity of consumers.  $\square$

We extend this logic and aggregate the entire consumer population while assuming that consumers are distributed on a predisposition line $\Omega = [-\infty, \infty]$. This line is analogous to the Hotelling line $[0, 1]$, which represents the physical space occupied by consumers and firms (Hotelling 1929): if firm $A$ and firm $B$ occupied respective positions 0 and 1 on the line, then a consumer located to the left of 0.5 would require less travel to purchase from firm $A$. To attract such consumers, firm $B$ must price sufficiently lower than firm $A$ to compensate for the additional travel cost. Similarly, a consumer on the predisposition line with $\Omega < 0$ is one who is favorably predisposed to product $A$. To attract this consumer, firm $B$ must overcome the "predisposition barrier" by offering sufficiently higher quality, $q_B > q_A$, or by pricing sufficiently lower if $q_B = q_A$. This so-called sufficiency margin is determined by the multiplicative term $\Omega\xi$, which represents the interaction of predisposition and ambiguity.

Without loss of generality, we can normalize the consumer population's size to 1. The demand is equivalent to the market share. Hence the heterogeneity in a population's predisposition level,

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$\Omega$, can be represented by a probability distribution with the density $h(\Omega)$ and the distribution function $H(\Omega)$.

Recall that a consumer will purchase product $A$ rather than product $B$ if and only if inequality (2) holds, or (equivalently)

$$\left( \frac{(p_A - p_B) - (q_A - q_B)}{\xi} \right) < -\Omega \iff \Omega < \left( \frac{(q_A - q_B) - (p_A - p_B)}{\xi} \right). \tag{4}$$

Note that, for a presumed quality difference and prices $(p_A, p_B)$, customer $i$ will not purchase product $A$ unless $\Omega_i$ is low enough. Since consumers vary in the strength of their predispositions, it follows that—for any given (identical) price, quality difference $(q_A - q_B)$, and ambiguity level $\xi$—some consumers will purchase $A$ while others purchase $B$. The demand curve for product $A$ with respect to its relative price $(p_A - p_B)$ is given by integrating each inequality in (4) over the predisposition line according to the density $h(\Omega)$. Our next proposition presents a demand curve that depends on both ambiguity and the probability distribution over the predisposition. (The demand curve is easily generalized to incorporate heterogeneous price–quality trade-offs $\lambda$ and heterogeneous ambiguity levels $\xi$; see Appendix A and Section 5.2, respectively.)
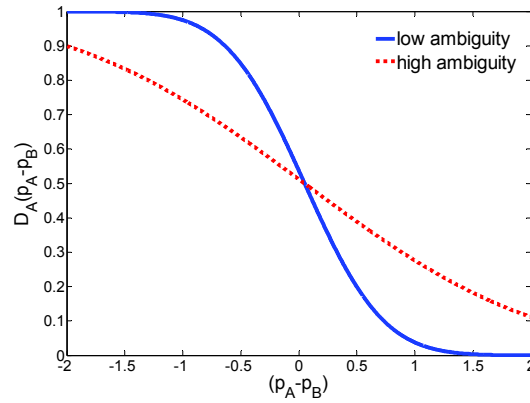
PROPOSITION 2 **(Effect of Predisposition and Ambiguity on the Demand Curve)**.
*For any $H(\Omega)$, demand $D_A(p_A, p_B)$ is increasing (resp. decreasing) in the degree of ambiguity if the price difference between two products $(p_A - p_B)$ is greater (resp. less) than the deserved premiums $(q_A - q_B)$. We have*

$$D_A(p_A, p_B) = \int_{-\infty}^{\frac{(q_A - q_B) - (p_A - p_B)}{\xi}} h(\Omega)\, d\Omega = H\left( \frac{(q_A - q_B) - (p_A - p_B)}{\xi} \right). \tag{5}$$

Figure 3 plots the product-$A$ demand curves for both high and low levels of ambiguity (when there is no ambiguity, the demand curve is a vertical line). The products being compared are of equal quality $(q_A = q_B)$, so firm $A$'s product merits a zero price premium. Here $\Omega$ is assumed to have a standard normal distribution, so neither firm has an advantage with respect to consumer predispositions. From Equation (5) it is clear that $D_A(p_A, p_B)$ rises with an increase in the deserved premium (i.e., when $q_A - q_B$ increases). If firm $A$ gradually increases the price of its product while firm $B$ maintains its current price, then firm $A$'s sales will decrease continuously rather than abruptly. The market share of each firm is thus a continuous function of the difference in price. Looking at where the figure shows $p_A - p_B = 0$, one can see that the slope of the demand becomes steeper—that is, demand becomes more elastic—when the level of ambiguity is low.

If firm $A$ is charging a price premium of 1 $(p_A - p_B = 1)$ then it can induce positive incremental demand when ambiguity about product quality is high. This is because a sufficient proportion of consumers are favorably predisposed to $A$ and will pay a premium owing to their positive benefit

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**Figure 3**    **Demand as a function of price difference for two products of equal quality.**



*Note.* This graph plots the demand for product $A$ as a function of $p_A - p_B$ when the quality of $B$ is equal to that of $A$ ($q_A = q_B$) and $\Omega$ is normally distributed. As the level of ambiguity decreases, consumers' benefit of doubt declines and they are then less willing to pay a price premium for either product; this dynamic makes the demand curve more elastic around $p_A = p_B$.

of doubt. Yet one effect of reduced ambiguity is a *decline* in those consumers' benefit of doubt. Thus they realize that the price premium for product $A$ is too high and then switch to the other product. Now suppose, to the contrary, that firm $A$ is charging a "negative price premium" of $-1$ ($p_A - p_B = -1$)—that is, offering a discount of 1 monetary unit. In this case, low ambiguity will increase product demand because the firm will attract consumers who at first were favorably predisposed to product $B$ but have come to realize that it no longer warrants a price premium.

## 4.    Equilibrium Market Outcomes

In this section we examine the price competition between two firms and investigate how predisposition levels and degree of ambiguity impact prices, profits, and market shares in equilibrium. We assume that the demand not satisfied by product $A$ is served by product $B$ (and vice versa). To simplify the presentation, we assume a zero cost and so each firm simultaneously maximizes its own profit by pricing its product: firm $A$ maximizes $p_A(D_A(p_A, p_B))$; and firm $B$ maximizes $p_B(1 - D_A(p_A, p_B))$. The price need not refer only to the posted price but also to the effective price (i.e., the posted price *minus* the value of any discounts, rebates, or extended warranties).

We begin in Section 4.1 by establishing the unique equilibrium outcomes as our unit of analysis. Then, in Section 4.2, we examine the sensitivity of equilibrium prices and profits to the distribution of predispositions in the population and the level of ambiguity in the product-market environment.

### 4.1.    Unique Equilibrium

In a competitive market setting, the firm may increase its profit by lowering its product's price and thereby capturing potential customers of its rival. In equilibrium, the prices set by firms $A$ and $B$

are such that neither firm wishes to change their price unilaterally. We shall use a simple example to illustrate the dynamics of price formation.

EXAMPLE 2. Suppose that $\Delta Q \equiv q_A - q_B = 0$ and that predispositions $\Omega$ are uniformly distributed in the population over the interval $[0, 1]$. This setup is similar to the competitive setting of a pioneering branded original drug (firm $B$) and its generic but chemically equivalent counterpart (firm $A$) in the pharmaceutical industry. From the demand expression in Equation (5) we obtain the linear demand curves $D_A(p_A, p_B) = \frac{p_B - p_A}{\xi}$ and $D_B(p_A, p_B) = 1 + \frac{p_A - p_B}{\xi}$. Applying the first-order conditions to the resulting quadratic profit functions, we arrive at the following best-response prices for each firm:

$$p_A^*(p_B) = \frac{p_B}{2}, \qquad p_B^*(p_A) = \frac{\xi + p_A}{2}.$$

Suppose there are many generic firms engaging in perfect competition among themselves and so their prices are constrained to be equal to their marginal cost (zero, for simplicity); that is, let $p_A = 0$. In this case the original firm would apply the best-response price $p_B^* = \xi/2$, resulting in market shares $D_A = D_B^* = 0.5$ and respective profits $\pi_A = 0$ and $\pi_B^* = \xi/4$. Now suppose instead that the generic drugs consolidate and one firm (firm $A$) competes with the original drug (firm $B$). The equilibrium prices $(p_A^*, p_B^*) = (\xi/3, 2\xi/3)$ can be found by solving for the fixed point. Thus we derive the market shares $D_A^* = 1/3$ and $D_B^* = 2/3$ as well as the profits $\pi_A^* = \xi/9$ and $\pi_B^* = 4\xi/9$.

Figure 4 illustrates the equilibrium dynamics by plotting the best-response prices of each firm on one graph. Observe that equilibrium prices depend on $\xi$, the level of ambiguity. If ambiguity $\xi = 0$ then competition would be fierce, driving prices closer to the origin (as in models of classical Bertand competition). In the presence of ambiguity $\xi$ about product quality, equilibrium prices will be strictly positive. It is clear also that, the greater is ambiguity, the higher the prices that both firms can charge and the more profits they will generate. □

We next examine the equilibrium that obtains with respect to the general class of distributions $H(\Omega)$ for which each firm's best-response prices can be found by applying the first-order conditions. The following assumption guarantees the existence of a unique pure-strategy equilibrium.

ASSUMPTION 4. *The distribution $H(y)$ is continuous and differentiable and is such that* (i) $\frac{h(y)}{1 - H(y)}$ *is increasing in $y$ and* (ii) $\frac{h(y)}{H(y)}$ *is decreasing in $y$.*

If we set $y = \left( \frac{(q_A - q_B) - (p_A - p_B)}{\xi} \right)$, then $H(y)$ denotes firm A's market share and $h(y)$ denotes the market share's rate of change. Therefore, these ratios capture the rate at which market share is transferred from one firm to the other after a price change. The greater the price difference $(p_A - p_B)$, the faster this rate of transfer. Assumption 4 ensures that an increase in price does not increase demand—as it might, for example, if price were viewed by consumers as a signal of high quality (Wathieu and Bertini 2007). Technically, the assumption states that the distribution $H$

**Figure 4**     **Formation of equilibrium prices.**
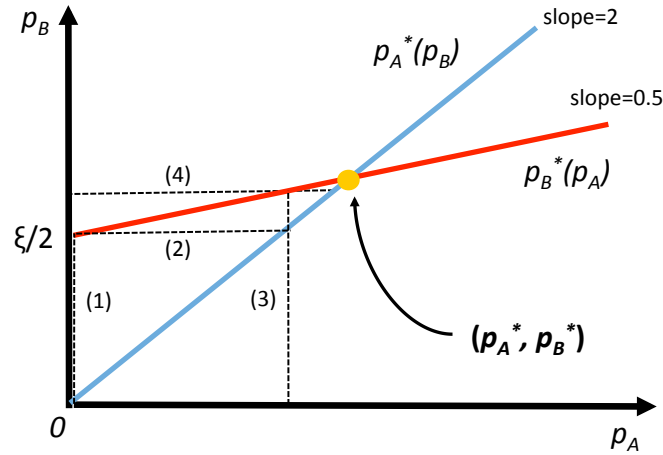


*Note.* Suppose firm $A$ sets $p_A = 0$. Then firm $B$ responds with its best-response price that maximizes profit $\pi_B$ (dashed line (1) in the graph). Given this price, firm $A$ then sets a higher price to increase its profit, $\pi_A$ (line (2)), which leads to yet another price from firm $B$ (3), and another increase in price from firm $A$ (4). There is a unique pair of prices $(p_A^*, p_B^*)$ at which neither firm benefits from a price change, and those are the equilibrium prices.

has an increasing hazard rate and a decreasing reversed hazard rate. For the uniform distribution used in Example 2, $H(\Omega) = \Omega$; hence $h(y)/(1 - H(y)) = 1/(1 - \Omega)$ and $h(y)/H(y) = 1/\Omega$, satisfying Assumption 4. Many other known distributions, including the beta distribution, satisfy this assumption (Block et al. 1997).

Next we establish the existence of unique and positive pure-strategy equilibrium prices.

THEOREM 2 (**Equilibrium Price and Market Share**). *For any predisposition distribution $H(\Omega)$ satisfying Assumption 4, there exists a unique pair of pure-strategy equilibrium prices $(p_A^*, p_B^*)$. Moreover, the equilibrium prices and market shares satisfy*

$$H\left(\frac{(q_A - q_B) - (p_A^* - p_B^*)}{\xi}\right) = \frac{p_A^*}{p_A^* + p_B^*}. \tag{6}$$

The equilibrium outcome depends not only on predisposition levels, which are distributed according to $H(\Omega)$ on the predisposition line, but also on the level of ambiguity $\xi$. If ambiguity is high enough, then the firm with a predisposition advantage—in the sense that more potential customers are favorably predisposed toward its products—can charge a higher price and will garner a higher market share than its rival. Similar equilibrium results have been obtained in the literature on promotions under brand loyalty (Rao 1986, Narasimhan 1988, Raju et al. 1990, Wernerfelt 1991, Villas-Boas 2004, Iyer et al. 2005, Baye and Morgan 2009). Our results refine extant insights by incorporating their dependence on the level of ambiguity. And rather than the mixed-strategy price distributions used to study promotion strategies, our model's unit of analysis is the pure-strategy equilibrium; that focus is appropriate for drawing implications about market outcomes.

The left-hand side of Equation (6) is the expression for the equilibrium market share for firm $A$, and it shows that prices and market shares are proportional in our equilibrium. According to Theorem 2, market outcomes are driven by an interaction between predisposition and ambiguity. We now examine the impact of predisposition and ambiguity in more detail.

## 4.2. Effect of Predisposition and Ambiguity on Market Outcomes

We start by examining a special setting in which the two firms sell products of equal quality and enjoy the same extent of favorable consumer predisposition.
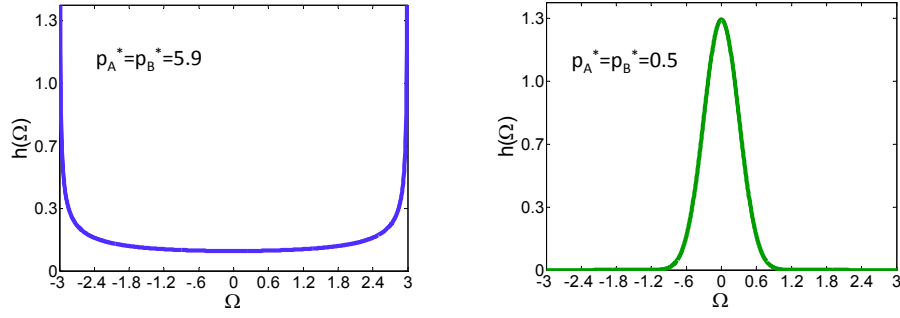
### 4.2.1. Symmetric Competition.
Note that even though the distribution of consumers along the predisposition line may be symmetric, it need not be uniform. For instance, buyers of golf clubs (e.g., Callaway vs. TaylorMade) may be more accurately described by a bimodal distribution along the predisposition line whereas buyers of batteries (e.g., Duracell vs. Energizer) may be more accurately described by a unimodal distribution centered around "neutral" ($\Omega = 0$). The following result describes the effect of predisposition density $h(\Omega)$ and ambiguity $\xi$ on the equilibrium.

COROLLARY 1 **(Symmetric Competition)**. *Suppose that $q_A = q_B$. Then, for any symmetric predisposition density $h(\Omega)$ satisfying Assumption 4, we have*

$$p_A^* = p_B^* = \frac{\xi}{2h(0)}, \qquad D_A^* = D_B^* = \frac{1}{2}. \tag{7}$$

Equations (7) reveal that, in symmetric competition, while the equilibrium demand remains constant, the equilibrium price increases proportionally with the degree of ambiguity $\xi$. Proposition 1 states that, for lower $\xi$, the price premium that customers are willing to pay for their preferred product is likewise lower. So when $\xi$ is low, a firm can induce its rival's customers to defect with only a small change in price. The result is intensified competition, which in turn leads to a lower equilibrium market price.

The equilibrium price is inversely proportional to $h(0)$, which corresponds to the height of the distribution's midpoint. A lower $h(0)$ value reflects more polarized predispositions, which can be related to the strength of predisposition commanded by each firm (see Figure 5). If each firm's customers exhibit strong predisposition ($h(\Omega)$ highly polarized), as in the figure's left panel, then there are more partisan customers than indifferent customers. Therefore, a firm that lowers the price of its product will attract only a small number of indifferent customers even as it sacrifices revenue from its large number of favorably predisposed customers. In this case, neither firm is inclined to make significant price reductions because each holds a quasi-monopolistic market position that yields a high market price. In contrast, if predisposition is low ($h(\Omega)$ concentrated around 0), as in the right panel of Figure 5, then there are more indifferent customers than partisan customers. Hence a firm that lowers its price will attract a large number of indifferent customers while sacrificing revenue from its small number of loyal customers. In this case the firms compete more intensely on price, which results in a relatively low equilibrium price.

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**Figure 5** **Symmetric distributions $h(\Omega)$ on the predisposition line $\Omega$.**



*Note.* The left panel, where $h(\Omega) = \frac{1}{6} \cdot \text{beta}\left(\frac{\Omega+3}{6} \mid 0.5, 0.5\right)$, represents the case of many partisan customers; the right panel, where $h(\Omega) = \frac{1}{6} \cdot \text{beta}\left(\frac{\Omega+3}{6} \mid 50, 50\right)$, represents the case of many indifferent customers. Although the two products are of equal quality ($q_A = q_B$), the left panel's equilibrium price ($p_A^* = p_B^* = 5.9$) is higher than the right panel's ($p_A^* = p_B^* = 0.5$). Here the ambiguity in information is set to $\xi = 3$.

**Figure 6** **Asymmetric distributions $h(\Omega)$ on the predisposition line $\Omega$.**
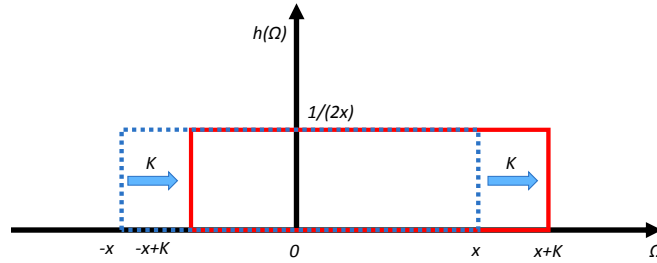


*Note.* The graph illustrates a uniform distribution on $[-x, +x]$ that is right-shifted by the amount $K$.

**4.2.2. Asymmetric Competition.** Here we consider the asymmetric competitive setting. To make the intuition precise, we suppose that predispositions are uniformly distributed[5] in $\Omega \in [-x + K, \, x + K]$ (see Figure 6). A positive (resp., negative) $K$ implies a more favorable predisposition toward firm $B$ (resp., firm $A$). Our next corollary identifies the equilibrium prices and market shares when predispositions are asymmetrically distributed in the population.

COROLLARY 2 (**Asymmetric Competition**). *Suppose that $h(\Omega) = 1/2x$, with $\Omega \in [-x + K, \, x + K]$ for some $K$ and some $x > 0$, and that the degree of ambiguity $\xi > 0$. Then*

$$(p_A^*, p_B^*) = \left( \frac{\Delta Q}{3} + \left( x - \frac{K}{3} \right)\xi, \, -\frac{\Delta Q}{3} + \left( x + \frac{K}{3} \right)\xi \right), \tag{8}$$

$$(D_A^*, D_B^*) = \left( \frac{1}{2} + \frac{1}{6x}\left( \frac{\Delta Q}{\xi} - K \right), \, \frac{1}{2} - \frac{1}{6x}\left( \frac{\Delta Q}{\xi} - K \right) \right). \tag{9}$$

Equations (8) and (9) clearly show how the quality difference $\Delta Q$, the distribution $(x, K)$ of predispositions, and the level of ambiguity $\xi$ interact to produce the equilibrium. One can see in particular that, in equilibrium, the price premium for product $A$ is

[5] For any general distribution $H$ satisfying Assumption 4, equilibrium prices can be found via computational methods.

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$$p_A^* - p_B^* = \frac{2}{3}(\Delta Q - K\xi).$$

The price premium for product $A$ observed in the market closely resembles the price premium equation given in Proposition 1 for an individual consumer. Firm $A$ can command a higher price in equilibrium if and only if its quality advantage *exceeds* its predisposition disadvantage (i.e., $p_A^* > p_B^*$ if and only if $\Delta Q > K\xi$). We also find that, as the level of ambiguity $\xi$ declines, the effect of predispositions also declines and so the equilibrium price premium is increasingly governed by differences in product quality.

Multiplying the equilibrium prices and demand of Equations (8) and (9) yields the following expressions for each firm's profits in equilibrium:

$$p_A^* D_A^* = \frac{\Delta Q}{3}\left(1 - \frac{K}{3x}\right) + \frac{1}{2}\left[\frac{\xi}{x}\left(\frac{K}{3} - x\right)^2 + \left(\frac{\Delta Q}{3}\right)^2 \frac{1}{x\xi}\right], \tag{10}$$

$$p_B^* D_B^* = -\frac{\Delta Q}{3}\left(1 + \frac{K}{3x}\right) + \frac{1}{2}\left[\frac{\xi}{x}\left(\frac{K}{3} + x\right)^2 + \left(\frac{\Delta Q}{3}\right)^2 \frac{1}{x\xi}\right]. \tag{11}$$

We next examine how the individual dimensions of asymmetry ($\Delta Q$ and $K$) and their combination affect market outcomes.

**Case 1: $\Delta Q = 0$ and $K > 0$.** Suppose there is asymmetry only in consumer predispositions, and firm $A$ is disadvantaged by those predispositions (note, $K \leq 3x$ to ensure $p_A^* \geq 0$). Then the expressions (10) and (11) for equilibrium profits reduce to

$$(p_A^* D_A^*, p_B^* D_B^*) = \left(\frac{\xi}{2x}\left(\frac{K}{3} - x\right)^2, \frac{\xi}{2x}\left(\frac{K}{3} + x\right)^2\right).$$

It is intuitive that increasing $K$ will increase the predisposition advantage of firm $B$ and thereby increase its equilibrium profit while reducing firm $A$'s. Note that if $K = 0$ then we have the profits obtained by Corollary 1 for symmetric competition.

**Case 2: $\Delta Q > 0$ and $K = 0$.** Suppose there is asymmetry only in product quality. If $A$ has a quality advantage, then the equilibrium equations (8) and (9) reduce to

$$(p_A^*, p_B^*) = \left(\frac{\Delta Q}{3} + x\xi, -\frac{\Delta Q}{3} + x\xi\right), \qquad (D_A^*, D_B^*) = \left(\frac{1}{2} + \frac{\Delta Q}{6x\xi}, \frac{1}{2} - \frac{\Delta Q}{6x\xi}\right).$$

Just as in the symmetric setting, higher ambiguity $\xi$ increases the equilibrium prices for both firms. Yet examining the equilibrium demand expressions reveals that increased ambiguity $\xi$ is detrimental to firm $A$ but beneficial to firm $B$. In particular, the ratio $\Delta Q/\xi$ implies that consumers are reluctant to migrate toward the higher-quality product $A$ when ambiguity $\xi$ is high. In other words, ambiguity $\xi$ protects the lower-quality firm $B$ from losing customers to the higher-quality firm $A$.

We see that, at $\xi = \Delta Q/3x$, both $p_B^*$ and $D_B^*$ are equal to 0. Since firm $B$ is naturally opposed to charging a negative price, it follows that competition exists only when ambiguity $\xi \geq \Delta Q/3x$. In this region of ambiguity, the equilibrium profit expressions (10) and (11) reduce to

$$(p_A^* D_A^*, p_B^* D_B^*) = \left( \frac{\Delta Q}{3} + \frac{1}{2}\left[ x\xi + \left(\frac{\Delta Q}{3}\right)^2 \frac{1}{x\xi} \right], -\frac{\Delta Q}{3} + \frac{1}{2}\left[ x\xi + \left(\frac{\Delta Q}{3}\right)^2 \frac{1}{x\xi} \right] \right).$$

It is noteworthy that we find, regardless of $\Delta Q$'s magnitude, that both firms will secure higher profits when ambiguity is greater.

**Case 3: $\Delta Q > 0$ and $K > 0$.** Finally, we consider the setting where firm $A$ has a quality advantage but a predisposition disadvantage. This scenario is akin to the setting of an incumbent ($B$) and a new entrant ($A$). In this case, the equilibrium profit equations (10) and (11) can be evaluated in their current form. As before, we consider the region of ambiguity that ensures firm $B$ remains in competition; here $\xi \geq \Delta Q/(3x + K)$.

The comparative statics with respect to predisposition distribution $\Omega$ (represented by $K$) and ambiguity level $\xi$ are illustrated by the left and the right panels of Figure 7 respectively. We observe that the incumbent (firm $B$) always benefits from having more favorably predisposed consumers (higher $K$), and from having greater ambiguity $\xi$. For the higher quality new entrant (firm $A$), while it is always beneficial to have less unfavorably predisposed consumers (lower $K$), ambiguity has a non-monotonic effect on its profit. This scenario is illustrated in the right panel of Figure 7. Two forces are at play here: on the one hand, low ambiguity $\xi$ results in new entrant $A$ attaining higher market share at the expense of the incumbent $B$; on the other hand, high ambiguity $\xi$ results in a high equilibrium price because the price competition is less intense. When ambiguity $\xi = \Delta Q/|K - 3x|$, the new entrant's profit is at its lowest level because neither condition—high market share nor less intense price competition—obtains. Thus the equilibrium profit for higher quality new entrant (firm $A$) is high when the level of ambiguity $\xi$ is either low or high, whereas that for incumbent (firm $B$) increases with ambiguity $\xi$.

In settings involving simple quality measures and therefore low ambiguity (e.g., battery life), the higher-quality firm should do well. For complex products with non-overlapping attributes and multiple interpretations of quality and therefore with high ambiguity, an incumbent advantaged by consumer predispositions will likely find the new entrant unthreatening.

If a firm could unilaterally change ambiguity $\xi$, then eliminating it entirely would be ideal for the new entrant. In reality, however, that approach is not feasible because (a) a complete resolution of quality uncertainty is too difficult to achieve (Muthukrishnan 1995) and (b) ambiguity depends also on the *competitor's* actions. Recall from our iPhone versus Android illustration that there is almost always mixed evidence, from various sources, concerning product qualities. Firms may adopt information provision strategies for marginally reducing (or increasing) the current level of ambiguity. The managerial insights derived from marginal analysis are discussed in section 6.1.

**Figure 7**    Equilibrium profits as a function of predisposition ($\Omega$) and ambiguity ($\xi$) about product quality.
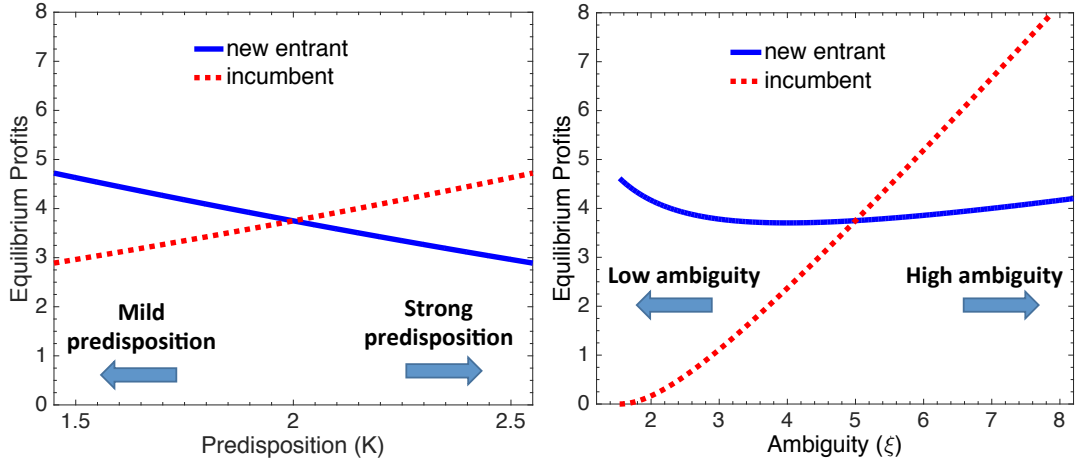


*Note.* The product offered by the new entrant (firm $A$) is of higher quality, $q_A - q_B = 10$, but the incumbent (firm $B$) has predisposition advantage ($h(\Omega)$ is uniformly distributed with $x = 1.5$, $K > 0$). In the left panel, ambiguity level is fixed at $\xi = 5$, and the predisposition advantage of the incumbent $K$ is altered. In the right panel, the predisposition advantage of the incumbent is fixed at $K = 2$, and ambiguity level $\xi$ is altered.

## 5.  Extensions

In this section, we provide two extensions of our basic model. In the first extension, we derive equilibrium market outcomes in the presence of loyal customers. These loyal customers stick to one brand and do not switch. In the second extension, we examine the impact of fully informed customers on market outcomes.

### 5.1.  Presence of Loyal Customers

So far, we have assumed that demand not satisfied by product A is served by product B (and vice versa). For some product markets, there are customers who only consider a particular brand that they are loyal to when making a purchase choice. These customers will purchase the product if the price is below their willingness-to-pay, and leave the market otherwise. For example, some buyers of electric cars may only consider one brand (e.g., Tesla) and leave the market without considering a competing brand (e.g., Chevy Bolt) if price is too high. We examine the impact of loyal customers on market outcomes.

Let $\ell_A$ (resp., $\ell_B$) denote the proportion of customers who are "loyal" to firm A (resp., firm B). We assume that the $\ell_A$ (resp., $\ell_B$) segment of customers have a common threshold for their willingness-to-pay, $\bar{p}_A$ (resp., $\bar{p}_B$) above which they leave the market. The two firms thus compete on price for the remaining $1 - \ell_A - \ell_B$ proportion of customers. The demand curves for firm A and firm B are,

$$
D_A(p_A, p_B) = \begin{cases} \ell_A + (1 - \ell_A - \ell_B) H\left(\frac{(q_A - q_B) - (p_A - p_B)}{\xi}\right) & \text{if } p_A \leq \bar{p}_A, \\ 0 + (1 - \ell_A - \ell_B) H\left(\frac{(q_A - q_B) - (p_A - p_B)}{\xi}\right) & \text{if } p_A > \bar{p}_A. \end{cases}
$$

$$D_B(p_A, p_B) = \begin{cases} \ell_B + (1 - \ell_A - \ell_B)\left(1 - H\left(\frac{(q_A - q_B) - (p_A - p_B)}{\xi}\right)\right) & \text{if } p_B \leq \bar{p}_B, \\ 0 + (1 - \ell_A - \ell_B)\left(1 - H\left(\frac{(q_A - q_B) - (p_A - p_B)}{\xi}\right)\right) & \text{if } p_B > \bar{p}_B. \end{cases}$$

Notice that because of the loyal segment, $D_B \neq 1 - D_A$. We study the symmetric case (as in §4.2.1) for simplicity. (We defer readers to the online appendix for the asymmetric setting.) Specifically, we consider the setting of $q_A = q_B$ and symmetric $h(0)$, and assume that both firms have equal proportion of loyal customers ($\ell_A = \ell_B = \ell$). These loyal customers have a common reservation price $\bar{p}_A = \bar{p}_B = \bar{p}$, which is greater than the equilibrium market price without loyal customers as in Corollary 1 ($\bar{p} > \xi/2h(0)$). The resulting equilibrium prices and demands are given next.

PROPOSITION 3. *Let $q_A = q_B$, and suppose that the predisposition density $h(\Omega)$ is symmetric satisfying Assumption 4 and that $\ell_A = \ell_B = \ell$ and $\bar{p}_A = \bar{p}_B = \bar{p} > \xi/2h(0)$. Then,*

$$p_A^* = p_B^* = \min\left\{\frac{\xi}{2h(0)(1 - 2\ell)}, \bar{p}\right\}, \qquad D_A^* = D_B^* = \frac{1}{2}.$$

We observe that as the proportion of loyal customers $\ell$ increases, the equilibrium prices $p_A^*$ and $p_B^*$ increase towards $\bar{p}$. Thus, having more loyal customers mitigates the intensity of price competition and benefits both firms.

In product-market environments with largely indifferent customers (Figure 5, right panel), loyal customers improve the profitability of both firms. In the example in Figure 5, if each firm cultivates 10% loyal customers (e.g., through loyalty programs), then each will enjoy 25% boost in profits.

## 5.2. Presence of Fully Informed Customers

Our model has thus far assumed that all consumers have the same level $\xi$ of ambiguity. We now relax that assumption and examine how the presence of fully informed consumers affects market outcomes. For some categories of products, there are segments of consumers who are inherently more informed than the rest (e.g., experts for technology products, medical professionals for OTC drugs), and whose purchase decisions are based solely on the price–quality trade-off (i.e., they purchase the product with higher $q_i - p_i$, $i \in \{A, B\}$). All other consumer segments are less informed (i.e., $\xi > 0$) and rely on their predispositions when deciding about purchases.

Let $\gamma$ denote the proportion of customers who are fully informed. Then the demand curve (Equation (5)) becomes

$$D_A(p_A, p_B) = \begin{cases} (1 - \gamma)H\left(\frac{(q_A - q_B) - (p_A - p_B)}{\xi}\right) + \gamma & \text{if } p_A - p_B < q_A - q_B, \\ (1 - \gamma)H\left(\frac{(q_A - q_B) - (p_A - p_B)}{\xi}\right) & \text{otherwise.} \end{cases}$$

The presence of fully informed customers introduces a discontinuity in the firm's demand curve when $p_A - p_B = q_A - q_B$ because the entire $\gamma$ proportion of consumers switch from firm $A$ to

firm $B$. The implications are that both the profit and best-response price functions for each firm are discontinuous and that a unique equilibrium may no longer exist.

To explicate the conditions for existence of a unique equilibrium and to make our intuition precise, we revisit the uniform distribution used in Section 4.2 (Figure 6) and re-examine the results—now, in the presence of fully informed consumers, presented next.

PROPOSITION 4 (**Unique Equilibrium Conditions**). *Let $q_A \geq q_B$, and suppose that $h(\Omega) = 1/2x$ with $\Omega \in [-x + K, \ x + K]$ for some $K > 0$ and $x > 0$. Let $\xi > 0$. Then there exists a $\bar{\gamma} > 0$ such that the following statements hold.*

(i) *If $\gamma < \bar{\gamma}$, then a unique pure-strategy price equilibrium exists and*

$$(p_A^*, p_B^*) = \left( \frac{\Delta Q}{3} + \left[ \frac{3 + \gamma}{3(1 - \gamma)} x - \frac{K}{3} \right] \xi, \ -\frac{\Delta Q}{3} + \left[ \frac{3 - \gamma}{3(1 - \gamma)} x + \frac{K}{3} \right] \xi \right); \tag{12}$$

$$(D_A^*, D_B^*) = \left( \left( \frac{1}{2} + \frac{\gamma}{6} \right) + \frac{1 - \gamma}{6x} \left( \frac{\Delta Q}{\xi} - K \right), \ \left( \frac{1}{2} - \frac{\gamma}{6} \right) - \frac{1 - \gamma}{6x} \left( \frac{\Delta Q}{\xi} - K \right) \right). \tag{13}$$

(ii) *If $\gamma \geq \bar{\gamma}$, then there exists at least one mixed-strategy price equilibrium.*

By this proposition, a unique equilibrium can exist even in the presence of a fully informed customer segment. Suppose, for example, that $\Delta Q = 10$, $(x, K) = (1.5, 2)$, and $\xi = 6$; then there is unique equilibrium provided $\gamma < \bar{\gamma} = 0.35$. (The specific expression for $\bar{\gamma}$ is complex and is given in Equation (B-2) in Appendix B.) We remark that $\bar{\gamma}$ is increasing in the quality difference $\Delta Q$ and decreasing in ambiguity $\xi$. In other words: the more vertically differentiated the competing products or the less ambiguous is product quality, the more likely that a unique equilibrium exists. When qualities are equal ($\Delta Q = 0$), $\bar{\gamma}$ is smaller but still positive and increasing in the skewness $K$ of the predisposition distribution. It is only when *both* quality and predisposition levels are symmetric that the presence of even a few fully informed customers would lead to a mixed-strategy price equilibrium.

When $\gamma < \bar{\gamma}$, price competition results in a unique equilibrium for two reasons: first, because the $\gamma$ proportion of fully informed customers will all purchase from the higher-quality (or, if qualities are equal, from the lower-priced) firm $A$; second, because both firms understand that the competing firm $B$ cannot profit from luring those customers away by undercutting prices. In the resulting competitive dynamic, firm $A$—with its additional demand $\gamma$—has more to lose in margins by undercutting prices. Firm $B$ can more easily offset a decline in $\gamma$ demand by undercutting prices to acquire some of the less-informed customers. In equilibrium, the dynamics of this competition smooths out any lumpiness in the demand curve created by $\gamma$. In fact, it is easy to verify that the equilibrium prices and demands (12) and (13) continue to satisfy the relationship stated in Equation (6) of Theorem 2.

When $\gamma \geq \bar{\gamma}$, there is no unique pure-strategy price equilibrium because both firms find it profitable to compete for the $\gamma$ segment of consumers. For a given competing price, the firm can profitably undercut its rival's price to lure the $\gamma$ proportion of customers. Since both firms engage in price competition, there comes a price point at which one firm finds it more lucrative to raise its price—sacrificing the $\gamma$ proportion of customers yet making higher profits on its sales to predisposed customers. Given that increase in price by one firm, the competing firm will also find it more lucrative to increase its price. In this scenario, a mixed-strategy pricing equilibrium exists where each firm chooses a probability distribution of prices that maximize its expected profits.

One can compute the mixed-strategy price equilibrium, but it is analytically difficult to characterize and its meaning is unclear in our setting. We shall focus on the comparative statics of the unique equilibrium prices within $\gamma \in [0, \bar{\gamma})$. We next describe the properties of equilibrium prices with respect to $\gamma$.

COROLLARY 3 (**Comparative Statics w.r.t.** $\gamma$). *Suppose that* $h(\Omega) = 1/2x$, *with* $\Omega \in [-x + K, \, x + K]$ *for some* $K \geq 0$ *and* $x > 0$. *Let* $\xi > 0$ *and* $q_A \geq q_B$. *Then, for* $\gamma \in [0, \bar{\gamma})$:
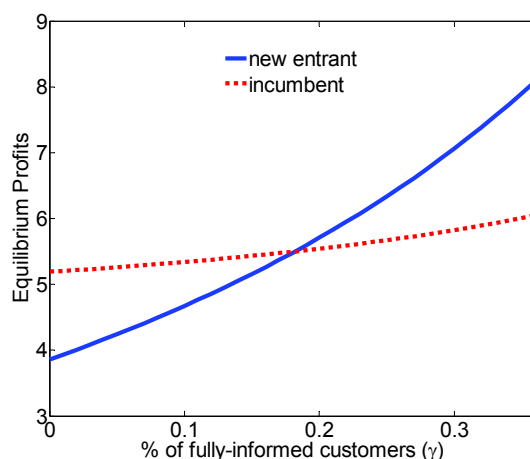
(i) *both* $p_A^*$ *and* $p_B^*$ *are increasing in* $\gamma$;

(ii) *the difference in price,* $p_A^* - p_B^*$, *is increasing in* $\gamma$.

Corollary 3 reveals that a higher proportion of fully informed customers leads to an increase in equilibrium prices for both firms. The price of a higher-quality new entrant's product increases faster than that of incumbent as the proportion of fully informed customers increases. Thus the fully informed customers serve to *reduce* the intensity of competition. This outcome runs counter to the prevailing belief that, when consumers are more informed, competition increases and so equilibrium prices and profits both decline (Chen et al. 2009).

Why do fully informed customers reduce price competition? First, an increase in $\gamma$ implies that firms compete on price for a shrinking segment of $(1 - \gamma)$ consumers because the $\gamma$ proportion of customers will purchase the higher quality product from firm $A$ in equilibrium. That is, both firms now have less to gain in demand by undercutting prices. Second, if $\gamma$ increases then a price reduction by the higher-quality firm $A$ results in loss of margins on the larger proportion of fully informed customers that it has secured, so firm $A$ is less aggressive in undercutting firm $B$'s price, which in turn enables the incumbent to retain its loyal customers at a higher price point.

Multiplying the expressions for equilibrium prices (12) and demands (13) yields each firm's profits in equilibrium. Figure 8 plots the equilibrium profits as a function of $\gamma$ for $\gamma \in [0, \bar{\gamma})$; here the setting is that of a higher-quality new entrant firm $A$ and an incumbent firm $B$ with a predisposition advantage (Case 3; see Section 4.2.2), where $\Delta Q > 0$ and $K > 0$. Figure 8 illustrates that equilibrium profits for *both* firms increase with an increase in the proportion of fully informed customers.

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**Figure 8    Equilibrium profits for both firms as the proportion γ of informed customers increases.**



*Note.* Firm $A$ (solid curve) has higher quality, and firm $B$ (dashed curve) has the predisposition advantage; predisposition is uniformly distributed. Parameters: $\xi = 6$, $q_A - q_B = 10$, $(x, K) = (1.5, 2)$.

# 6.    Discussion
## 6.1.    Managerial Insights

Ambiguity about product quality is an inherent characteristic of the product–market environment, and it can hardly ever be eliminated unilaterally by one firm. However, firms can marginally influence the degree of ambiguity by providing information. Our marginal analysis of the equilibrium results offer some interesting managerial insights for firms.

A marginal reduction in ambiguity $\xi$ has two effects: it reduces equilibrium prices by intensifying price competition; and it increases (resp. decreases) the market share of the higher-quality (resp. lower-quality) firm by making the quality difference more convincing. So in vertical competition, the *lower*-quality firm's optimal strategy is to seek a marginal increase in ambiguity because that raises the equilibrium price and also deters consumers from switching to the higher-quality product.

The *higher*-quality firm's strategy in this case is more nuanced. If no firm has a predisposition advantage then the higher-quality firm should, regardless of the quality difference, aim for a marginal increase in ambiguity. Yet if the higher-quality firm is at a predisposition disadvantage, as when a new entrant challenges an incumbent, then characteristics of the product–environment determine its approach to ambiguity. For products with simple measures of quality and so ambiguity is low (e.g., battery life), the higher-quality firm should seek a marginal reduction in ambiguity. For complex products with non-overlapping attributes and multiple interpretations of quality—in other words, when ambiguity is high—that firm may find it more profitable to tolerate ambiguity.

The presence of fully informed customers, who know the true quality, may reduce competition. In a vertically differentiated market, the entire segment of fully informed customers migrates to the higher-quality firm; that migration leaves a smaller customer base up for competition. Neither firm

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has an incentive to aggressively compete on price. The higher-quality firm, having secured the fully informed market segment, loses margin on these sales when it lowers the price. The lower-quality firm is content to retain a smaller market share and has limited capacity to lure customers from the competitor by undercutting the price.

Firms can also marginally influence consumer predispositions by effective advertising or brand management strategies. The degree of predisposition can be influenced by reward programs or benefits (Kim et al. 2001), previous purchases (Villas-Boas 2004), and appropriate persuasive advertising (Chen et al. 2009). Apart from the obvious notion that having more favorably predisposed consumers is beneficial, our results indicate the importance for firms of cultivating a loyal customer base *before* pursuing a rival's customer base—that is, the focus should be on making favorably predisposed consumers even more so. A customer base with a high degree of favorable predisposition protects against (modest) price cuts by competitors, since it is not induced to switch by those cuts. Furthermore, the firm can retain these loyal customers even when its rival offers a product of higher quality.

Predisposition and ambiguity influence a firm's information and brand management strategy. Improving predisposition always benefits a firm. The appropriate information strategies when evidence about quality is ambiguous depend on the prior opinion about a particular brand. Ambiguity tends to increase the preference for the established brand towards which the customer base is favorably predisposed. Muthukrishnan et al. (2009) find that under ambiguity subjects prefer the dominated established brands (e.g., Sony) over dominating less established brands (e.g., Toshiba). The strategy for the established brand is to leverage predisposition and exploit the potential for multiple interpretations of what constitutes high quality. Tesla's mystique and charismatic leader (Elon Musk) helps it attract a large customer base who is willing to pay a price premium for its brands. On April 1, 2016, Tesla unveiled its mass market affordable Model 3 car. Elon Musk positioned Model 3 as a "Sustainable Transport" that is needed to combat global warming. The initial estimate for the range per charge for the Model 3 is 225 miles with an entry price point of $35,000. China's BYD (stands for "Build Your Dreams") with investments from Warren Buffet, produces Model e6 with a range of 250 miles per charge and is priced at $31,000. Within two weeks of the introduction, Tesla's Model 3 booked orders for 400,000 cars that may take several years to fulfill. Premium brands like Tesla devise brand strategies so that consumers associate their brands with prestige and luxury. It is not in the interest of premium brands to invite comparisons on objective attributes and reduce ambiguity; instead, they exploit inertia in consumer choice.

In contrast, unknown or "underdog" brands need to encourage experimentation to reduce ambiguity. In early 2000s, a new comer to the coffee market, Keurig sent sales representatives into stores in large numbers to do live demonstrations. The strategy was to show consumers the convenience

of using a Keurig brewer and K-cup to make customized coffee in less than a minute. Ten years later, Keurig commanded over a billion dollars in sales.

The interaction effect—of consumer predisposition and ambiguity about quality—on consumer choice and market outcomes has not been sufficiently studied in the marketing science literature. It has been observed, for instance, that familiarity or name recognition (favorable predisposition) enables brand-name drugs to command a higher price than generic versions with the same active ingredients. Thus consumers pay higher prices for Bayer aspirin, Morton salt, and Windex glass cleaner (than for their generic equivalents) because there is ambiguity in the form of misinformation or doubt about the quality of generics and so the consumer anchors on her predisposition towards familiar, brand-name products. Fully informed consumers such as doctors, chefs, or professional window cleaners are more likely than the general public to buy generic products in their domain of expertise (Bronnenberg et al. 2015). The crux of our contribution is, in a nutshell, the joint influence of predisposition and ambiguity on consumer preference.

## 6.2.    Summary and Conclusion

Predisposition towards a product and inconclusive evidence about the quality of products are universal characteristics of most product–market environments. If evidence related to quality is ambiguous or inconclusive, then consumers behave in a boundedly rational manner: resorting to a heuristic whereby the products or services chosen are the ones toward which they are favorably predisposed. Although the interaction between ambiguity and predisposition in decision making has often been studied experimentally at the level of individual consumers, its effects on market outcomes are not well understood.

In this paper we develop a multi-attribute utility model to characterize boundedly rational consumers who must choose between products with ambiguous qualities. Our model captures the interaction between predisposition and ambiguity, and it yields the following expression:

$$\text{Price premium} = \text{Quality difference} - (\text{Predisposition} \times \text{Ambiguity}).$$

If a consumer is neutrally predisposed, or if there is no ambiguity about quality, then the consumer behaves as an expected utility maximizer. Yet because evidence about quality is ambiguous in most real-world situations, the model's multiplicative term plays an important role in choice.

Using this formulation as an anchor, we aggregate the varying predisposition levels across all consumers. The resulting demand curve depends not only on how predispositions are distributed but also on the level of ambiguity. In this way we build a rich model that links the roles of ambiguity and predisposition at the individual consumer level and that reveals—via the demand curve—their effect at the aggregated market level. Demand is more elastic when ambiguity is low and is sticky

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when ambiguity is high. Despite its richness, the model is simple enough to enable practical (i.e., computationally tractable) analyses of competitive market outcomes and of how they are affected by the interaction between predisposition and ambiguity. When competition is symmetric, firms command higher prices and make higher profits when ambiguity is high and the consumer base is partisan; when competition is asymmetric, closed-form solutions for equilibrium market outcomes are obtained when predispositions are uniformly distributed over the consumer population.

In equilibrium, the price premium observed in the market closely resembles the price premium calculated for an individual consumer; that premium depends on the quality difference and on the interaction of predisposition and ambiguity. Our conclusions about market outcomes are similar under a general distribution for predisposition levels, and marginal analysis of the equilibrium yields several managerial insights. In a vertically differentiated market, the higher-quality firm may decide not to reduce ambiguity at the margin. Moreover, the presence of (practically) fully informed customers may increase prices and profits for both firms.

The impact of predisposition and ambiguity on product choice at the individual consumer and firm levels is an important empirical question for marketing research. Our multi-attribute utility model can be used in probabilistic choice models—for example, the multinomial logit (MNL) model (Guadagni and Little 1983)—to aid empirical research and theory building. The validity of such a probabilistic choice model hinges on how reliably predisposition and ambiguity can be measured. The development of social media and of data analytics offer new opportunities for improving such measures. One can now assess predispositions by tracking consumers on the Internet via searches, chat rooms, social network sites, blogs, and product reviews; similarly, one could develop a scale of ambiguity that reflects the diversity of opinions expressed in written reviews. The consolidation of firms in the market research industry is making data sources that integrate such information at the consumer level more readily available. Hanssens et al. (2014) suggest that, notwithstanding increases in the amount of available information about consumer attitudes towards products, it is not entirely clear how firms can exploit such information to improve their marketing effectiveness. We believe that the model presented here could be fruitfully employed to aid such understanding and enhance marketing research and practice.

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## Appendix A:  Extension to Heterogeneous $\lambda$

We incorporate heterogeneous preferences about quality $\lambda$. The demand curve reflects those preferences, where higher (resp. lower) $\lambda$ implies a greater extent of quality (resp. price) consciousness in a consumer population. A consumer $i$ who is willing to pay $\lambda_i$ for a unit of quality will purchase product $A$ if and only if

$$\lambda_i q_A - p_A - \Omega_i \xi > \lambda_i q_B - p_B \iff (p_A - p_B) < \lambda_i(q_A - q_B) - \Omega_i \xi \iff \Omega_i < \frac{\lambda_i(q_A - q_B) - (p_A - p_B)}{\xi}.$$

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When the market size is normalized to 1, the expression for demand becomes

$$D_A(p_A, p_B) = P\left(\Omega_i < \frac{\lambda_i(q_A - q_B) - (p_A - p_B)}{\xi}\right),$$

whose value depends on the joint distribution of $(\lambda_i, \Omega_i)$. Let $F(\lambda, \Omega)$ and $f(\lambda, \Omega)$, respectively, denote the joint cdf and pdf. If $\lambda$ and $\Omega$ are independently distributed—so that $F = G \cdot H$—then the demand expression (7) in Proposition 2 becomes

$$
\begin{aligned}
D_A(p_A, p_B) &= \int\int_{\Omega < \frac{\lambda(q_A-q_B)-(p_A-p_B)}{\xi}} f(\lambda, \Omega)\, d\lambda\, d\Omega = \int_0^{+\infty} \int_{-\infty}^{\frac{\lambda(q_A-q_B)-(p_A-p_B)}{\xi}} f(\lambda, \Omega)\, d\Omega\, d\lambda \\
&= \int_0^{+\infty} g(\lambda) \int_{-\infty}^{\frac{\lambda(q_A-q_B)-(p_A-p_B)}{\xi}} h(\Omega)\, d\Omega\, d\lambda = \int_0^{+\infty} H\left(\frac{\lambda(q_A-q_B)-(p_A-p_B)}{\xi}\right) g(\lambda)\, d\lambda \\
&= \mathbb{E}_\lambda H\left(\frac{\lambda(q_A-q_B)-(p_A-p_B)}{\xi}\right).
\end{aligned}
\tag{A-1}
$$

The third equality is due to the independence assumption of $F = G \cdot H$, the fourth equality holds because the inner integral expression is the cdf, and the final equality holds because the expression represents the expectation. In sum, the new demand expression (A-1) is an *expectation* of the original demand expression (7) weighted for the different values of $\lambda$ in the population.

The simplicity of the demand expression (A-1) generalizes Theorem 2 as follows.

COROLLARY A.1 **(Equilibrium Price and Market Share)**. *For any predisposition cdf $H(\Omega)$ with infinite support and satisfying Assumption 4, there exists a unique pair of pure-strategy equilibrium prices $(p_A^*, p_B^*)$. Furthermore, if $\lambda$ and $\Omega$ are independent then the equilibrium prices and market shares satisfy*

$$\mathbb{E}_\lambda H\left(\frac{\lambda(q_A-q_B)-(p_A^*-p_B^*)}{\xi}\right) = \frac{p_A^*}{p_A^* + p_B^*}.\tag{A-2}$$

Suppose that $\Omega$ is uniformly distributed in $[-x+K, x+K]$ (see Figure 6). Revisiting Corollary A.1 allows us to hone our insight concerning the effect of heterogeneous price–quality trade-offs $\lambda$. More specifically: if $\lambda$ is distributed over an infinite support $[0, +\infty)$ (e.g., distributed exponentially) and if $\lambda$ and $\Omega$ are independently distributed, then the equilibrium equations (10) and (11) become

$$
\begin{aligned}
(p_A^*, p_B^*) &= \left(\frac{\mathbb{E}[\lambda]\Delta Q}{3} + \left(x - \frac{K}{3}\right)\xi, -\frac{\mathbb{E}[\lambda]\Delta Q}{3} + \left(x + \frac{K}{3}\right)\xi\right), \\
(D_A^*, D_B^*) &= \left(\frac{1}{2} + \frac{1}{6x}\left(\frac{\mathbb{E}[\lambda]\Delta Q}{\xi} - K\right), \frac{1}{2} - \frac{1}{6x}\left(\frac{\mathbb{E}[\lambda]\Delta Q}{\xi} - K\right)\right).
\end{aligned}
$$

Note that with higher $\mathbb{E}(\lambda)$, firm $A$'s price and demand ($p_A^*$ and $D_A^*$) increase while firm $B$'s price and demand ($p_B^*$ and $D_B^*$) decrease. A higher $\mathbb{E}(\lambda)$ implies that there are, on average, more quality-conscious than price-conscious consumers. In such case, the quality difference $\Delta Q$ becomes more important to consumers; in equilibrium, that shift benefits the higher-quality firm.

The simplicity of our expression for incorporating heterogenous $\lambda$ is driven by the assumption of independence. Whether predisposition $\Omega$ and the price–quality trade-off $\lambda$ are indeed independent is an empirical question that we leave for future work.

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## Appendix B:   Proofs

*Proof of Proposition 1.*   The statement clearly follows from taking the derivative of (2).   □

*Proof of Theorem 1.*   Assumption 1 is the difference independence condition (Dyer and Sarin 1979) and yields $V(p, q, \Omega, \xi) = v_1(p, q) + v_2(\Omega, \xi)$. Assumptions 2 and 3 imply that $v_2(\Omega, \xi) = \Omega \cdot \xi$. The multiplicative form for $v_2$ follows directly from Bleichrodt et al. (1997).   □

*Proof of Proposition 2.*   As a cdf, $H(\cdot)$ is increasing. Hence the comparative statics result follows from taking the derivative of $\frac{q_A - q_B - (p_A - p_B)}{\xi}$ with respect to $\xi$.   □

*Proof of Theorem 2.*   See the following proof of Corollary A.1, of which this is a special case.   □

*Proof of Corollary A.1.*   Assumption 4 ensures that, for any $\lambda$, the profit expressions $p_A(D_A(p_A - p_B))$ and $p_B(1 - D_A(p_A - p_B))$ are strictly unimodal in $p_A$ and $p_B$, respectively. The unique optimal prices $p_A^*$ and $p_B^*$ are given by the respective first-order conditions of $p_A(D_A(p_A - p_B))$ and $p_B(1 - D_A(p_A - p_B))$:

$$-\frac{1}{p_A^*} = \frac{\frac{\partial}{\partial p_A^*} \mathbb{E}_\lambda H\left(\frac{\lambda(q_A - q_B) - (p_A^* - p_B)}{\xi}\right)}{\mathbb{E}_\lambda H\left(\frac{\lambda(q_A - q_B) - (p_A^* - p_B)}{\xi}\right)}, \qquad \frac{1}{p_B^*} = \frac{\frac{\partial}{\partial p_B^*} \mathbb{E}_\lambda H\left(\frac{\lambda(q_A - q_B) - (p_A - p_B^*)}{\xi}\right)}{1 - \mathbb{E}_\lambda H\left(\frac{\lambda(q_A - q_B) - (p_A - p_B^*)}{\xi}\right)}. \tag{B-1}$$

Hence it is clear that (a) the strategy sets $p_A$ and $p_B$ are closed and compact and (b) the combination of their best responses forms a contraction. As a result, there exists a unique pair of pure-strategy equilibrium prices $(p_A^*, p_B^*)$ (cf. Friedman 1990, Thm. 3.4).

Because (B-1) consists of two equations with two unknowns, we can combine the two expressions to obtain

$$\frac{\mathbb{E}_\lambda H\left(\frac{\lambda(q_A - q_B) - (p_A - p_B)}{\xi}\right)}{p_A} = \frac{1 - \mathbb{E}_\lambda H\left(\frac{\lambda(q_A - q_B) - (p_A - p_B)}{\xi}\right)}{p_B} \Leftrightarrow \mathbb{E}_\lambda H\left(\frac{\lambda(q_A - q_B) - (p_A - p_B)}{\xi}\right) = \frac{p_A^*}{p_A^* + p_B^*}.   □$$

*Proof of Corollary 1.*   From the necessary conditions prescribed by Equation (6) it follows that $p_A^* = p_B^*$, which implies that $\Theta = \frac{(q_A - q_B) - (p_A - p_B)}{\xi} = 0$. At this value of $\Theta$ we have $H(0) = 1 - H(0) = 0.5$ (by symmetry), so $D_A^* = D_B^* = 0.5$. This, in turn, implies the first-order conditions

$$-\frac{1}{p_A} = -\frac{h(0)}{\xi} \cdot \frac{1}{2} \quad \text{and} \quad \frac{1}{p_B} = -\frac{h(0)}{\xi} \cdot \frac{1}{2},$$

which correspond to Equations (7).   □

*Proof of Corollary 2.*   Given the linear demand curves, we can write quadratic profit expressions in terms of prices as follows:

$$p_A D_A = p_A \int_{-x+K}^{\Theta} \frac{1}{2x}\, dz = p_A \left[\frac{1}{2x}(\Theta) + \left(\frac{x - K}{2x}\right)\right], \qquad p_B D_B = p_B \int_{\Theta}^{x+K} \frac{1}{2x}\, dz = p_B \left[\left(\frac{x + K}{2x}\right) - \frac{1}{2x}(\Theta)\right];$$

as before, $\Theta = \frac{\Delta Q - (p_A - p_B)}{\xi}$. Taking the first-order conditions of each expression now yields the respective firms' best-response prices:

$$p_A^*(p_B) = \left(\frac{\Delta Q + p_B}{2}\right) + \left(\frac{x - K}{2}\right)\xi, \qquad p_B^*(p_A) = -\left(\frac{\Delta Q - p_A}{2}\right) + \left(\frac{x + K}{2}\right)\xi.$$

Solving this system of equations gives us the unique fixed point $(p_A^*, p_B^*)$ in Equation (8) that characterizes the equilibrium prices. Substituting these expressions into those for the linear demand curves then yields the unique equilibrium demands $(D_A^*, D_B^*)$ calculated by Equation (9).   □

*Proof of Proposition 3.*   Taking the first order conditions for the profit for firm $A$ *with* loyal customer,

$$\frac{\partial}{\partial p_A} p_A D_A(p_A, p_B) = 0 \Leftrightarrow \frac{\partial}{\partial p_A}\left[p_A \ell + p_A(1 - 2\ell)H\left(\frac{q_A - q_B - (p_A - p_B)}{\xi}\right)\right] = 0$$

$$\Leftrightarrow \ell + (1 - 2\ell)\left[-\frac{p_A}{\xi} h\left(\frac{q_A - q_B - (p_A - p_B)}{\xi}\right) + H\left(\frac{q_A - q_B - (p_A - p_B)}{\xi}\right)\right] = 0$$

$$\Leftrightarrow \ell + (1 - 2\ell)H(0) = (1 - 2\ell)\frac{p_A}{\xi} h(0) \Leftrightarrow p_A = \frac{\xi}{2h(0)(1 - 2\ell)},$$

**Figure B-1**     **Three profit curves that result in three different expressions for optimal (profit-maximizing) prices.**
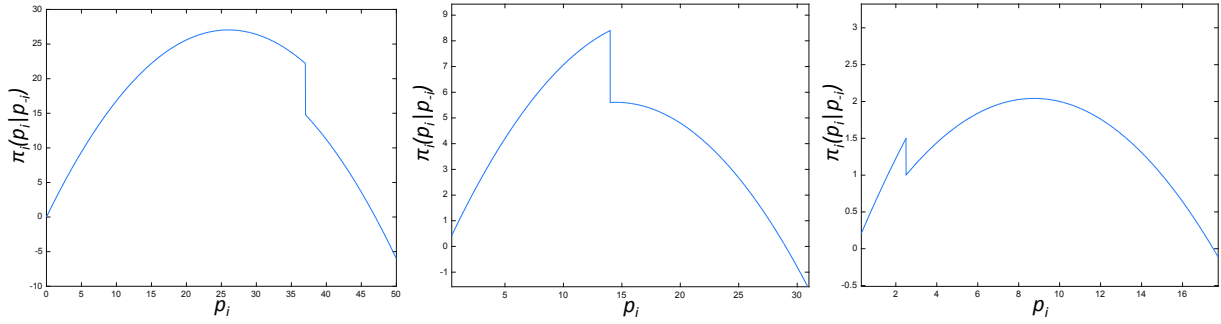


where the penultimate equivalence is because by symmetry $\frac{(q_A-q_B)-(p_A-p_B)}{\xi} = 0$, and the final equivalence follows from $H(0) = 1 - H(0) = 0.5$. In similar manner, we can find that $p_B = \frac{\xi}{2h(0)(1-2\ell)}$. This leaves firms with optimal profits $\frac{\xi}{2h(0)}\left(\frac{1}{2} + \frac{\ell}{1-2\ell}\right)$.

Next we show that it is never optimal for firms to lose the loyal customer segment $\ell$. Without the loyal segment, from Corollary 1, the optimal $p_A^* = p_B^* = \frac{\xi}{2h(0)}$, and the optimal profit is $\frac{\xi}{2h(0)}\left(\frac{1}{2} - \ell\right)$, which is clearly less than $\frac{\xi}{2h(0)}\left(\frac{1}{2} + \frac{\ell}{1-2\ell}\right)$ with loyal customers. If $\bar{p} < \frac{\xi}{2h(0)(1-2\ell)}$, the profit with loyal customers at price $\bar{p}$ is $\bar{p}\left(\frac{1}{2}\right)$, which is also greater than $\frac{\xi}{2h(0)}\left(\frac{1}{2} - \ell\right)$, since $\bar{p} > \frac{\xi}{2h(0)}$ by assumption. Thus, neither firms will price above $\bar{p}$. Finally, since the prices are equivalent, by symmetry it follows that $D_A^* = D_B^* = 0.5$.     $\square$

*Proof of Proposition 4.*   (i) We begin by establishing Equation (12). We first derive the following expression for the best-response prices ($\Delta Q \equiv q_A - q_B$):

$$
p_A^*(p_B) = \begin{cases} \frac{\xi(x-K)}{2} + \frac{\Delta Q + p_B}{2}, & p_B < \frac{\xi(1+3\gamma)x - (1-\gamma)K - \sqrt{8x\gamma((1+\gamma)x - (1-\gamma)K)}}{1-\gamma} - \Delta Q, \\ p_B + \Delta Q, & p_B \in \left[\frac{\xi(1+3\gamma)x - (1-\gamma)K - \sqrt{8x\gamma((1+\gamma)x - (1-\gamma)K)}}{1-\gamma} - \Delta Q, \ \xi\left(\frac{1+\gamma}{1-\gamma}x - K\right) - \Delta Q\right], \\ \frac{\xi\left(\frac{1+\gamma}{1-\gamma}x - K\right)}{2} + \frac{\Delta Q + p_B}{2}, & p_B > \xi\left(\frac{1+\gamma}{1-\gamma}x - K\right) - \Delta Q; \end{cases}
$$

$$
p_B^*(p_A) = \begin{cases} \frac{\xi(x+K)}{2} + \frac{p_A - \Delta Q}{2}, & p_A < \frac{\xi(1+3\gamma)x + (1-\gamma)K - \sqrt{8x\gamma((1+\gamma)x + (1-\gamma)K)}}{1-\gamma} + \Delta Q, \\ p_A - \Delta Q, & p_A \in \left[\frac{\xi(1+3\gamma)x + (1-\gamma)K - \sqrt{8x\gamma((1+\gamma)x + (1-\gamma)K)}}{1-\gamma} + \Delta Q, \ \xi\left(\frac{1+\gamma}{1-\gamma}x + K\right) + \Delta Q\right], \\ \frac{\xi\left(\frac{1+\gamma}{1-\gamma}x + K\right)}{2} + \frac{p_A - \Delta Q}{2}, & p_A > \xi\left(\frac{1+\gamma}{1-\gamma}x + K\right) + \Delta Q. \end{cases}
$$

A discontinuous drop can occur in three different points (see Figure B-1), leading to three different expressions for the optimal price. After finding the expressions for the optimal prices in each case, we identify the conditions for each case.

In the left panel of Figure B-1, the optimal price corresponds to the optimal price when there *is* a $\gamma$ proportion of customers, which is found by taking the first-order condition of the profit expression with $\gamma$, or $p_A\left((1-\gamma)H\left(\frac{\Delta Q - (p_A - p_B)}{\xi}\right) + \gamma\right)$; thus we write

$$
\frac{\partial \pi_A(p_A, p_B)}{\partial p_A} = 0 \Leftrightarrow \frac{-(1-\gamma)p_A}{2\xi x} + \frac{(1-\gamma)\left(x - K + \frac{\Delta Q - (p_A - p_B)}{\xi}\right)}{2x} + \gamma = 0 \Leftrightarrow p_A = \frac{\xi\left(\frac{1+\gamma}{1-\gamma}x - K\right)}{2} + \frac{\Delta Q + p_B}{2}.
$$

In the case of the middle panel of Figure B-1, the optimal price is given by $p_A^* = p_B + \Delta Q$—that is, just before the discontinuous drop in profit occurs.

In the right panel of Figure B-1, the optimal price corresponds to that when there is *not* a $\gamma$ proportion of customers, which is found by taking the first-order condition of the profit expression without $\gamma$, or $p_A(1-\gamma)H\left(\frac{\Delta Q - (p_A - p_B)}{\xi}\right)$; then

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$$\frac{\partial \pi_A(p_A, p_B)}{\partial p_A} = 0 \Leftrightarrow \frac{-(1-\gamma)p_A}{2\xi x} + \frac{(1-\gamma)\left(x - K + \frac{\Delta Q - (p_A - p_B)}{\xi}\right)}{2x} = 0 \Leftrightarrow p_A = \frac{\xi(x-K)}{2} + \frac{\Delta Q + p_B}{2}.$$

We now identify the conditions for each case. First, $p_A^* = \frac{\xi\left(\frac{1+\gamma}{1-\gamma}x - K\right)}{2} + \frac{\Delta Q + p_B}{2}$ (left panel of Figure B-1) if

$$\frac{\xi}{2}\left(\frac{1+\gamma}{1-\gamma}x - K\right) + \frac{\Delta Q + p_B}{2} < \Delta Q + p_B \iff p_B > \xi\left(\frac{1+\gamma}{1-\gamma}x - K\right) - \Delta Q.$$

Next, if $p_B \leq \xi\left(\frac{1+\gamma}{1-\gamma}x - K\right) - \Delta Q$ then $p_A^* = p_B + \Delta Q$ or $p_A^* = \frac{\xi}{2}(x - K) + \frac{\Delta Q + p_B}{2}$. The comparison of interest is that between the profit *with* $\gamma$, when $p_A = p_B + \Delta Q$ (middle panel of Figure B-1), and the profit *without* $\gamma$, when $p_A = \frac{\xi}{2}(x - K) + \frac{\Delta Q + p_B}{2}$ (right panel of Figure B-1). We have

$$\pi_A^{(a)} = p_A\left[\frac{1-\gamma}{2x}\left(x - K + \frac{\Delta Q + p_B}{\xi}\right) + \gamma\right] - \frac{1-\gamma}{2\xi x}p_A^2 = \left(\frac{1+\gamma}{2} - \frac{(1-\gamma)K}{2x}\right)[p_B + \Delta Q],$$

$$\pi_A^{(b)} = p_A\left[\frac{1-\gamma}{2x}\left(x - K + \frac{\Delta Q + p_B}{\xi}\right)\right] - \frac{1-\gamma}{2\xi x}p_A^2$$

$$= \frac{(1-\gamma)(x-K)^2\xi}{8x} + \frac{(1-\gamma)(x-K)}{4x}(\Delta Q + p_B) + \frac{1-\gamma}{8\xi x}(\Delta Q + p_B)^2;$$

$$\pi_A^{(a)} > \pi_A^{(b)} \iff 0 > \xi^2(x-K)^2 - 2\xi\left(\frac{1+3\gamma}{1-\gamma}x - K\right)(\Delta Q + p_B) + (\Delta Q + p_B)^2.$$

By the quadratic formula, the RHS is 0 when

$$p_B + \Delta Q = \frac{2\xi\left(\frac{1+3\gamma}{1-\gamma}x - K\right) \pm \sqrt{4\xi^2\left(\frac{1+3\gamma}{1-\gamma}x - K\right)^2 - 4 \cdot 1 \cdot \xi^2(x-K)^2}}{2} = \frac{\xi\left[(1+3\gamma)x - (1-\gamma)K \pm \sqrt{8x\gamma(x + x\gamma - (1-\gamma)K)}\right]}{1-\gamma}.$$

Therefore: if $p_B < \frac{\xi\left[(1+3\gamma) - (1-\gamma)K - \sqrt{8x\gamma(x + x\gamma - (1-\gamma)K)}\right]}{1-\gamma} - \Delta Q$, then $\pi_A^{(a)} > \pi_A^{(b)}$ and $p_A^* = \frac{\xi}{2}(x - K) + \frac{\Delta Q + p_B}{2}$ (right panel of Figure B-1); if

$$\frac{\xi\left[(1+3\gamma)x - (1-\gamma)K - \sqrt{8x\gamma(x + x\gamma - (1-\gamma)K)}\right]}{1-\gamma} < \Delta Q + p_B < \xi\left(\frac{1+\gamma}{1-\gamma}x - K\right)$$

$$\leq \frac{\xi\left[(1+3\gamma)x - (1-\gamma)K + \sqrt{8x\gamma(x + x\gamma - (1-\gamma)K)}\right]}{1-\gamma},$$

then $p_A^* = p_B + \Delta Q$ (middle panel of Figure B-1).

We complete the proof of part (i) by establishing Equation (13). Observe that, when the curve $p_A^*(p_B)$ is inverted and plotted on the $(p_A, p_B)$-space, there are only two scenarios that can lead to a unique fixed point; see Figure B-2.

Given that $q_A > q_B$, we shall examine the left panel of Figure B-2. The unique point at which the two curves overlap occurs when firm $A$ maximizes its price with $\gamma$ (slope = 2) and when firm $B$ maximizes its price without $\gamma$ (slope = 1/2); that is,

$$p_A^*(p_B) = \frac{\xi}{2}\left(\frac{1+\gamma}{1-\gamma}x - K\right) + \frac{\Delta Q + p_B}{2}, \qquad p_B^*(p_A) = \frac{\xi}{2}(x + K) + \frac{p_A - \Delta Q}{2}.$$
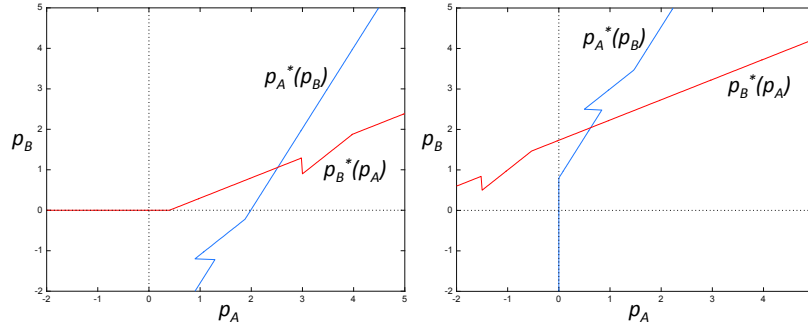
Solving this system of two equations and two unknowns, we obtain

$$p_A = \xi\left(\frac{3+\gamma}{3(1-\gamma)}x - \frac{K}{3}\right) + \frac{\Delta Q}{3} \quad \text{and} \quad p_B = \xi\left(\frac{3-\gamma}{3(1-\gamma)}x + \frac{K}{3}\right) - \frac{\Delta Q}{3}.$$

For the two curves to have a unique fixed point, the optimal price curve $p_A^*(p_B)$ with $\gamma$ must intersect the optimal price curve $p_B^*(p_A)$ without $\gamma$. This occurs when the point of intersection $p_A^*$ is less than the point at which $p_B^*(p_A)$ transitions from a slope of 1/2 to a slope of 1; that is,

$$\left(\frac{3+\gamma}{3(1-\gamma)}x - \frac{K}{3}\right)\xi + \frac{1}{3}\Delta Q < \frac{\xi\left[(1+3\gamma)x + (1-\gamma)K - \sqrt{8x\gamma((1+\gamma)x + (1-\gamma)K)}\right]}{1-\gamma} + \Delta Q$$

**Figure B-2** **Two possible fixed points between best-response prices. The horizontal axis denotes $p_A$ and the vertical axis denotes $p_B$. The (blue) curves, which include curves of slope 2, represent the inverted $p_A^*(p_B)$; the (red) curves, which include curves of slope $1/2$, represent $p_B^*(p_A)$.**



$$\Longleftrightarrow \frac{\xi\left[3\sqrt{2x\gamma((1+\gamma)x+(1-\gamma)K)}-(4\gamma x+2(1-\gamma)K)\right]}{1-\gamma} < \Delta Q$$

$$\Longleftrightarrow \gamma < \bar{\gamma} \triangleq \arg\max_{\gamma}\left\{\frac{\xi\left[3\sqrt{2x\gamma((1+\gamma)x+(1-\gamma)K)}-(4\gamma x+2(1-\gamma)K)\right]}{1-\gamma} < \Delta Q\right\}. \qquad \text{(B-2)}$$

Note that $\bar{\gamma}$ is well-defined because the fraction in the set expression is monotonically increasing in $\gamma$. Under this condition, the equilibrium difference between prices is given by

$$p_A^* - p_B^* = \frac{3+\gamma}{3(1-\gamma)}x\xi - \frac{K}{3}\xi - \frac{3-\gamma}{3(1-\gamma)}x\xi - \frac{K}{3}\xi + \frac{2}{3}\Delta Q = \frac{2}{3}\left(\frac{\gamma}{1-\gamma}x\xi - K\xi + \Delta Q\right).$$

Using this equilibrium price difference, we derive the following equilibrium demand for products $A$ and $B$:

$$D_A^* = \frac{1-\gamma}{2x}\left(x - K + \left(\frac{\Delta Q}{\xi} - \frac{2}{3\xi}\left(\frac{\gamma}{1-\gamma}x\xi - K\xi + \Delta Q\right)\right)\right) + \gamma = \left(\frac{1}{2}+\frac{\gamma}{6}\right) + \frac{1-\gamma}{6x}\left(\frac{\Delta Q}{\xi} - K\right);$$

$$D_B^* = \frac{1-\gamma}{2x}\left(x + K - \left(\frac{\Delta Q}{\xi} - \frac{2}{3\xi}\left(\frac{\gamma}{1-\gamma}x\xi - K\xi + \Delta Q\right)\right)\right) = \left(\frac{1}{2}-\frac{\gamma}{6}\right) - \frac{1-\gamma}{6x}\left(\frac{\Delta Q}{\xi} - K\right).$$

(ii) The structure of our "discontinuous reward" duopoly game satisfies the three sufficient conditions for its existence (as outlined in Dasgupta and Maskin 1986, Thm. 5). In particular: (1) the discontinuity is restricted to symmetric cases, $p_A - p_B = q_A - q_B$; (2) it is "lower semi-continuous" (so that, from the point of discontinuity, a slight price reduction results in a discontinuous increase in profit); and (3) $(\pi_A + \pi_B)(p_A, p_B)$ is continuous in $p_A$ and $p_B$. $\quad\square$

*Proof of Corollary 3.* (i) From the expressions for $p_A^*$ and $p_B^*$ it is clear that

$$\frac{\partial p_A^*}{\partial \gamma} > 0 \iff \frac{\partial}{\partial \gamma}\left(\frac{3+\gamma}{3-3\gamma}\right) > 0 \iff \frac{3(1-\gamma)\cdot 1 - (3+\gamma)(-3)}{(3-3\gamma)^2} > 0 \iff 3(1-\gamma) + 3(3+\gamma) > 0;$$

$$\frac{\partial p_B^*}{\partial \gamma} > 0 \iff \frac{\partial}{\partial \gamma}\left(\frac{3-\gamma}{3-3\gamma}\right) > 0 \iff \frac{3(1-\gamma)\cdot (-1) - (3+\gamma)(-3)}{(3-3\gamma)^2} > 0 \iff -3(1-\gamma) + 3(3+\gamma) > 0.$$

(ii) Since $p_A^* - p_B^* = \frac{2}{3}\left(\frac{\gamma}{1-\gamma}x\xi - K\xi + (q_A - q_B)\right)$, it follows that

$$\frac{\partial(p_A^* - p_B^*)}{\partial \gamma} > 0 \iff \frac{\partial}{\partial \gamma}\left(\frac{\gamma}{1-\gamma}\right) > 0 \iff \frac{(1-\gamma)\cdot 1 - \gamma(-1)}{(1-\gamma)^2} = \frac{1}{(1-\gamma)^2} > 0. \quad \square$$