Product Reviews and Competition in Markets for Repeat Purchase Products

XINXIN LI, LORIN M. HITT, AND Z. JOHN ZHANG

XINXIN LI is an assistant professor of operations and information management at the School of Business, University of Connecticut. She received her Ph.D. from the Wharton School, University of Pennsylvania. Her research interests lie at the intersection of information systems and marketing. Her current research examines the economics of online word of mouth and competition in electronic markets. Her work appears in *Information Systems Research* and *MIS Quarterly.*

LORIN M. HITT is the Class of 1942 Professor at the Wharton School, University of Pennsylvania. His work focuses on the productivity of information technology investments and the economics of electronic business. He received his Ph.D. in Management from MIT and his Sc.B. and Sc.M. in electrical engineering from Brown University. He is currently serving as the co-departmental editor for information systems at *Management Science* and is on the editorial board of the *Journal of Management Information Systems.*

Z. JOHN ZHANG is a professor of marketing and Murrel J. Ades Professor at the Wharton School, University of Pennsylvania. He earned a B.S. in engineering automation and philosophy of science from Huazhong University of Science and Technology (China), a Ph.D. in history and sociology of science from the University of Pennsylvania, and a Ph.D. in economics from the University of Michigan. Dr. Zhang's research focuses on competitive pricing strategies and the design of pricing structures. He has published numerous articles in top marketing and management journals on various pricing issues. He serves as associate editor for the *Journal of Quantitative Marketing.* He is also an area editor for *Marketing Science* and is on the editorial board for the *Journal of Marketing.*

ABSTRACT: This paper examines how information provided by online reviews influences firms' pricing strategy for repeat purchase products. It is commonly understood that online reviews can reduce consumer uncertainty about product characteristics and, therefore, have the potential to increase product demand and firm profits. However, when considering repeat purchase products, online reviews have an additional effect in that they can alter consumers' propensity to switch among products, which can intensify price competition and lead to lower profits. The strength of these potentially offsetting effects depends on the informativeness of consumer reviews, which is a function of both objective review accuracy and the ability of consumers to obtain information from reviews when their idiosyncratic preferences over product characteristics might differ from the preferences of reviewers. The interplay of these competing effects results in an S-shaped relationship between the quality of reviews and firm profits. There exists an optimal level of consumer informedness from the firms' perspective, and competing firms may have incentives to facilitate consumer reviews in some markets but not

in others. Given firms' strategic pricing, consumers may also be worse off as review informativeness increases.

IN RECENT YEARS, REVIEW WEB SITES AND ONLINE FORUMS have become a low-cost channel for consumers to share product evaluations for a wide assortment of products. Although these services provide many of the same functions as traditional word-of-mouth communication [19], information exchanged online is anonymous and unprecedented in scale and reach. According to a survey conducted by Forrester Reseach [3], as of October 2008, almost half of U.S. online consumers read product reviews at least once a month and 19 percent posted reviews online. Similar results were found in a survey done by Deloitte's Consumer Products group [29]—almost two-thirds of consumers read consumer-written product reviews on the Internet, and 69 percent of them share the reviews with friends, family, or colleagues, thus amplifying their effect.

This opportunity for large-scale experience sharing among consumers and for information gathering by consumers has the effect of reducing uncertainty about the attributes of new products or services. This is especially true for products whose utility cannot be fully known before purchase (such as experience goods), and when a consumer cannot try all products before making a purchase. In those cases, reviews can alter consumers' buying behavior by enabling them to find products that fit their idiosyncratic preferences. Indeed, consumer-generated reviews are widely reported to directly influence consumer purchase decisions [29], to be more valuable than expert reviews [11, 30], to have a greater influence on purchasing decisions than traditional media [15], and to have a significant effect on offline purchase behavior [30].

In this paper, we construct a game-theoretic model to examine how the ability of reviews to alter consumer informedness affects competitive pricing levels for repeat purchase products. By *consumer informedness,* we mean the extent to which consumers are able to ascertain their idiosyncratic utility for a product they have not used. In our product reviews context, we operationalize this concept as the probability that a potential buyer receives a correct signal about the value of an untried product from reading reviews of that product [9]. Reviews that enable consumers to update their beliefs about utility to be closer to their true utility are described as *informative,* consistent with prior literature [6]. Our approach differs from prior research on product reviews, as we focus on repeat purchase products, which has not been examined previously, and build on prior research that allows the informativeness of reviews to vary due to idiosyncratic consumer preferences.

For firms, empowering consumers with more information can be a mixed blessing. On the one hand, increasing the amount of information available about a product or service may increase the willingness to pay on the part of consumers who have not tried the product or service, thus having the effect of increasing demand and firm profit. We call this effect *demand enhancement.* Demand enhancement has been the primary focus of prior work, including both analytical studies [1, 6, 27] and empirical studies

[7, 9, 13, 24]), and is potentially relevant to any type of product, regardless of whether it is a single or a repeat purchase.

On the other hand, repeat purchase products have the unique characteristic that consumer information can also influence product-switching behavior, generating two additional competitive effects not present for single-purchase products [5, 23, 34]. First, reviews can provide information about products that consumers have not previously tried, thereby reducing the switching cost that arises due to uncertainty about product value or characteristics. Positive reviews, in particular, can encourage switching, which will cause firms to compete more aggressively for customers that use competitors' products, thus lowering industry profits. We refer to this effect as *switching risk reduction.* Second, consumers can also receive unfavorable signals about the value of competitors' products either because the reviews accurately reflect poor product quality or because of reviewer bias or error that leads a high-quality product to receive negative reviews. Negative reviews on competing products can enhance loyalty as they decrease the expected utility of switching, enabling firms to increase prices for their loyal customers and earn greater profits. We refer to this effect as (expected) *switching benefit reduction.* The ultimate impact of consumer reviews on firm profitability for repeat purchase products is therefore contingent on the relative strength of these three effects, which are mediated by consumer preferences, quality uncertainty, and the informativeness of reviews.

Reviews may not be fully informative for at least three reasons. First, reviewers may make errors or otherwise provide imperfect reviews. Second, product reviews may be influenced by deliberate forum manipulation in which firms pay reviewers to offer favorable reviews. However, prior analytical results [12, 26] suggest that this may not make reviews less informative because high-quality firms may have the greatest incentives to engage in forum manipulation so that high-quality products still have higher ratings even when firms invest in forum manipulation.

Finally, even when reviews are truthful and fully accurate, they may still not be fully informative if preferences between reviewers and a review user differ. This may be especially important for experience goods and services where consumer fit is critical. For example, two people who went to the same restaurant and ordered the same food might report diametrically opposite evaluations due to innately personal preferences for service, portion size, spiciness, ambience, and so forth. For a consumer who does not know the preferences of these two anonymous reviewers, it is hard to determine which review correctly indicates the level of satisfaction that the consumer would experience with the food. Therefore, there is always a chance that the consumer will receive an inaccurate signal from reading reviews. This is in contrast to traditional offline word of mouth, in which recommendations are provided by people whose preferences a consumer might understand (e.g., family or friends) or there is an opportunity for dialog to determine how the recommendation was arrived at. The tendency of online review sites to report summary measures (e.g., the average "star rating" at Amazon.com) and for consumers to rely on these summary measures instead of reading the context or investigating the reviewers makes it even more likely that a mismatch in preferences introduces errors in consumer decisions when they utilize online reviews. Prior work on word-of-mouth communication suggests that the persuasiveness of a message depends

on the similarity between the source of the message and the reader [21, 28, 31, 33], and unobservable preference differences between online reviewers and consumers using online reviews have been demonstrated to adversely affect consumers [24].

Product reviews can have different effects on firm profitability depending on the level of review informativeness. In this paper, we find that in some cases a shift from no information to perfect information on product value can "level the playing field" between tried and untried products, increasing competition and lowering profits due to *switching risk reduction.* For the same market, a shift from no information to partial information through moderately informative reviews can lead to increased profits due to *demand enhancement* or *switching benefit reduction.*

Thus, we show that there is a nonmonotonic relationship between consumer informedness and firm profitability; at low initial levels of informedness, *switching benefit reduction* dominates and profits are increasing as reviews become more informative. When reviews are moderately informative, the *switching risk reduction* effect dominates, yielding a negative relationship between increased informativeness and profits. Very informative reviews can give rise to *demand enhancement* where firms benefit from increasing review accuracy, although profits may not reach the same levels experienced at lower levels of consumer informedness. Consequently, firms may have an optimal level of consumer informedness that maximizes their profits. This optimal level may be neither full information nor complete uninformedness. The key managerial insight from this observation is that firms might want to facilitate reviews in some markets but not others. The model described in this paper identifies the factors that affect this choice.

Literature Review

This study contributes to the emerging stream of research on online product reviews. A number of empirical studies have documented the relationship between online product evaluations and product sales in different product categories. In the book industry, Chevalier and Mayzlin [7] demonstrated that the differences between consumer reviews posted on Barnes & Noble's and Amazon.com's Web sites relate positively to the differences in book sales through the two sites. Several follow-up studies further examined the mediation effects of other factors on the relationship of reviews and sales, such as the preference discrepancy between early and later buyers [24], the matching in geographic location between reviewers and users of the reviews [17], and the "helpfulness" votes of the reviews [14]. In the motion picture and television industries, Godes and Mayzlin [18] showed a strong relationship between the popularity of a television show and the "dispersion" of conversations about the television show across online consumer communities. Dellarocas et al. [13] incorporated the sentiment of word of mouth into a product diffusion model and found that the average rating of online consumer reviews is a better predictor of future movie revenues than other measures they considered. In contrast, Duan et al. [16] focused on the opposite causal relationship and found that the number of online reviews influences box office sales. In the beer industry, Clemons and his colleagues [10] found that the average rating of reviews and the strength of the most positive quartile of reviews have a significant

effect on the growth of craft beers. In the hotel industry, Clemons and Gao [9] showed that consumers exhibit loss aversion when selecting among moderate-quality hotels. While these studies provide empirical evidence on the connection between reviews and sales, they generally do not consider optimal pricing or firm profitability, and most examine single-purchase products such as movies or books, rather than repeat purchase products or do not consider repeat purchase dynamics.

In contrast to abundant empirical work, analytical studies of online reviews have been limited. McFadden and Train [27] found that when prices are assumed to be fixed, learning from others may delay the adoption of new products and enhance the sales of popular products while hurting the producers of niche products. Chen and Xie [6] showed that firms have incentive to help disseminate consumer reviews only when the firm's target market is sufficiently large and that reviews affect firms' optimal product assortment and information provision policies. Both of these studies focused on monopoly markets in which competition effects are not a concern. One recent series of studies considered the competitive effects of reviews [12, 26], but it examined single-purchase products with homogeneous consumer preferences and stressed the incentives of competing firms to manipulate reviews, rather than characterizing the competitive implications of truthful but imperfect reviews.

Our work differs from the aforementioned studies by introducing competition, modeling the dynamics of repeat purchase, and examining the implications of heterogeneous consumer preferences and review informativeness. Some prior work did consider repeat purchase products (e.g., studies of television shows, beer, and hotels [9, 10, 18]), but repeat purchase dynamics typically played no role in these models. Thus, the emphasis of prior work has been on characterizing the implications of what we have described as *demand enhancement.* By including the information effects of prior consumer product experience directly in the model, we can also examine how reviews enhance or reduce uncertainty-related switching risk or switching benefits, all of which are recognized in practice as important issues in competition among firms that have an existing customer base [5, 23, 34]. Incorporating the mediating effects of review informativeness further enables us to recognize for the first time the nonmonotonic effect of reviews on price competition as review informativeness increases. These issues may be especially important as online markets increasingly facilitate the trade of services and information goods in which consumers have long-term purchase relationships and products may be horizontally differentiated and have strong experience goods characteristics. Markets with these characteristics include travel (especially hotels), health care, retail financial services, skin care and cosmetics, restaurants, spas and salons, beers and wines, golf and health clubs, home and professional services, and tutoring and education centers, as well as products sold online with repeat purchase contracts, such as subscriptions.

Model

IN THIS SECTION, WE INTRODUCE OUR MODEL and analyze the effects of reviews on consumer choice, pricing strategies, firm profitability, and consumer surplus. Definitions of all notations used in our model appear in Table 1.

Table 1. Definitions of notations

Notation	Definition
q_i^j	The value of product j to consumer i
v	The value of a product if it matches a consumer's preference
a	The potential market size of matched consumers for each product
t	Explicit switching cost
p_n^j	Firm j's price at period n
D_n^j	Firm j's demand at period n
π_n^j	Firm j's profit at period n
δ	Intertemporal discount factor, which is assumed to equal 1
θ	Informativeness of reviews; $1/2 \leq \theta \leq 1$
P_+	The probability that a random consumer gets a positive (i.e., "matched") signal from reviews on an untried product
P_-	The probability that a random consumer gets a negative (i.e., "unmatched") signal from reviews on an untried product
$X_+ v$	The expected value of the untried product if a consumer gets a positive (i.e., "matched") signal from reviews
$X_- v$	The expected value of the untried product if a consumer gets a negative (i.e., "unmatched") signal from reviews
$\bar{a}_1, \bar{a}_2$	Thresholds for a
T_1, T_2	Thresholds for t/v
$\bar{\theta}_1, \bar{\theta}_2$	Thresholds for θ

Model Setup

Consider two competing firms, A and B, producing two experience goods (A and B, respectively) at zero marginal cost. The two products are substitutes and are consumed in unit quantity. We assume q_i^j ($j \in \{A, B\}$) measures the value of product j to consumer i, such as the effectiveness of a medicine or the voice quality of a wireless phone, which can be observed only after consumption. We allow q_i^j to be different across consumers; that is, different consumers may perceive the value of the same product differently. For tractability, we treat this type of consumer "fit" as dichotomous—q_i^j is modeled as a Bernoulli distribution, which takes value v with probability a and value 0 with probability $(1 - a)$. If $q_i^j = v$, we say product j matches consumer i's taste. If $q_i^j = 0$, we say product j does not match consumer i's taste. Thus, a captures the potential market size of each product, and also indicates the risk of getting a mismatched product for a random consumer. If a is large, then we are describing competition between "mass-market" products that are acceptable for most consumers (e.g., Coke and Pepsi). When a is small, we considering a market that consists of niche products (e.g., craft-brewed beer).

   We assume q_i^A and q_i^B are independent and constant over time; that is, we allow the existence of consumers who like both product A and product B. To illustrate, consider two restaurants serving different food. Some consumers may enjoy only one of them, but other consumers may like them both. Similarly, if we consider two wireless ser-

vice providers, depending on where the consumers live, some of them can have good voice quality only from one provider, but for others, both providers may deliver good voice quality. This approach provides a parsimonious model of consumer tastes, accommodates a wide variety of actual market conditions, and is consistent with prior work (e.g., [6, 34]).

Because we are interested in characterizing competition among firms when consumers have a purchase history, we assume that firms A and B have a symmetric installed customer base. Firm A's customers have used product A before, but not product B. Similarly, firm B's customers have used product B before, but not product A. This is consistent with optimal ex ante location in differentiated product competition (e.g., Hotelling [22] or Salop [32] models), although we do not model the initial product location decision explicitly. At a random time in the future, both firm A's and firm B's customers reenter the market a single time over the horizon of the model and select between product A and product B based on their prices at the time and expected product value. A consumer purchases at most one unit of either product at each purchase occasion. If neither product provides a nonnegative expected utility for a consumer, he or she may exit the market without making any purchase. It should be noted that our single-reentry assumption ensures that no consumer making a choice has previously experienced both products. While this is restrictive, it is unlikely to be a practical concern as this simply rules out markets in which it is viable for consumers to try all products first before settling on a long-term purchase. In such a market, reviews cannot play any role because they provide no incremental value over the consumers' own experiences. This assumption is consistent with prior work on competition in repeat purchase products (e.g., [34]).

Consumers incur an explicit cost t when switching products. Because we are modeling the relationship between value uncertainty and product choice, we treat the explicit switching cost parameterized by t as a characteristic of the product or market, unrelated to consumer informedness. For example, it takes time, effort, or direct expenses to set up a new account, to get acquainted with a new service provider, or to terminate an existing relationship or contract [5, 23]. The remaining risk or benefits of switching products that arise from value uncertainty of untried products are captured in our model endogenously as part of the consumer choice process. Thus, t can be interpreted as the "explicit" switching cost faced by a consumer even when there is no value uncertainty and the consumers are fully informed. The relative size of t over v determines the relative importance of the explicit switching cost compared to product value. If consumer i is in firm j's customer base (and so has used product j before), the net surplus or utility from consuming product j for consumer i is $q_i^j - p^j$. If consumer i is not in firm j's customer base (and so has not used product j before), the net surplus or utility from consuming product j for consumer i is $q_i^j - t - p^j$. Here, p^j is the price charged by firm j.

To model the situation in which firms can adjust price at any time, we subdivide time into an infinite number of small time periods. These time periods are indexed by n ($n = 0, 1, 2, ...$). Without loss of generality, we normalize the market size in each period as 1. Firms A and B take turns choosing prices. The alternating move assumption

is meant to capture the idea that a firm is able to respond to the price change of the competing firm with minimal but nonnegligible delay.[1] Accordingly, in odd-numbered periods n, firm A chooses its price, which remains unchanged until period $n + 2$. Similarly, firm B chooses its prices only in even-numbered periods. Consumers (who purchased A or B in the past) reenter the market with equal probability in any period. In period n, consumers who reenter the market in this period make purchase decisions based on the current prices p_n^A and p_n^B, and each firm selects the optimal price to optimize its intertemporal profit $\Sigma_{s=0}^{\infty} \delta^s \pi_{n+s}^j$, where π_n^j is firm j's profit in period n, and δ is the intertemporal discount factor. Due to technological innovations in retail pricing, such as bar codes, online retailing, and competitive information systems, firms can adjust prices and respond to competitors' prices rapidly. Consequently, we assume that the time that elapses between consecutive periods is minimal and thus the discount factor δ can be very close to 1 from the perspective of a price setter. Accordingly, for simplicity, we assume $\delta = 1$ in the following analysis.

Consumer Reviews and Product Valuation

Consumers know exactly their valuation of the product they bought before, but not the value of the other, untried product. Product reviews written by others can therefore provide information about the value of the untried product. From reading product reviews, a consumer obtains a signal of product value for the product he or she did not buy previously. Consistent with the binary nature of preferences, consumers can obtain a binary signal of whether the product fits their preferences ("matched") or not ("unmatched").

Product reviews can be noisy or uninformative in the sense that the signal provided by these reviews might mislead a "matched" consumer to consider the product to be "unmatched" before purchase and vice versa. This uninformativeness can be caused either by imperfection in the review process, such as reviewer error or forum manipulation [12, 26], or by differences in consumer preferences [24]. Higher informativeness in our model corresponds to better information as defined by Blackwell [4], and our consumer reasoning process is consistent with Bayesian updating. As in Chen and Xie's [6] approach, we define the informativeness of the reviews as the probability of receiving a correct signal about the value of the other product from these reviews, denoted by parameter θ. If the product matches a consumer's preference, he or she will receive a "matched" signal from reviews with probability θ and an "unmatched" signal from reviews with probability $(1 - \theta)$. Similarly, if the product does not match a consumer's preference, he or she will receive an "unmatched" signal with probability θ and a "matched" signal with probability $(1 - \theta)$.[2]

Let P_+ represent the probability that a *randomly chosen* consumer (the product matches his or her taste with probability a) gets a "matched" (positive) signal from reviews, and let P_- denote the probability that the consumer gets an "unmatched" (negative) signal. Then $P_+ = a\theta + (1 - a)(1 - \theta)$ and $P_- = a(1 - \theta) + (1 - a)\theta$. Naturally, we have $P_+ + P_- = 1$. We assume that the signal provided by the reviews is always somewhat informative in the sense that a "correct" signal is more likely than

an incorrect signal (otherwise the consumer can simply reverse the signal he or she gets, interpreting a "matched" signal as indicating "unmatched"). Thus, without loss of generality, we assume $1/2 \leq \theta \leq 1$,[3] which ensures that the signal is more likely to be correct. If $\theta = 1$, the reviews are perfectly informative, equivalent to the perfect information scenario in which the consumers know the value of the untried product perfectly before purchase. If $\theta = 1/2$, the reviews are completely uninformative (i.e., consumers are not able to get any additional information from the signal because the signal has an equal probability of being correct or incorrect), equivalent to the no-reviews scenario in which the consumers receive no information on the value of the untried product from the reviews.

Consistent with prior studies [6, 34], we assume that consumers and firms have common knowledge of the parameters t, v, a, and θ. If a consumer gets a "matched" signal from the reviews, he or she knows there is a probability $(1 - a)(1 - \theta)$ that the untried product does not match his or her taste and he or she simply received an inaccurate signal. Applying Bayes's rule, the consumer knows that the untried product will indeed match his or her preference with a probability of

$$\frac{a\theta}{a\theta + (1-a)(1-\theta)}.$$

The consumer therefore adjusts his or her expected value for the untried product conditional on receiving the "matched" (positive) signal as

$$X_+ v = \frac{a\theta}{a\theta + (1-a)(1-\theta)} v.$$

Similarly, if the consumer receives an "unmatched" signal, he or she knows the probability that the untried product matches his or her preference is

$$\frac{(1-a)\theta}{a(1-\theta) + (1-a)\theta},$$

which yields an expected value of

$$X_- v = \frac{(1-a)\theta}{a(1-\theta) + (1-a)\theta} v.$$

Thus, consumers can be divided into eight segments, based on their prior product purchase (A or B), whether the product that they tried matches their preference (value of the current product is v or 0), and the review signal that they receive from reading reviews on the untried product (positive or negative). For ease of exposition, we have numbered each of these segments 1 through 8 and will refer to the segment numbers in the following discussion. Table 2 presents the segment number, the segment size, and the consumers' expected utility from consuming product A and product B. To illustrate the segmentation, segment 1 represents a consumer who previously purchased product A, whose preferences match product A, and who receives a "matched" signal for product B.

Table 2. Consumer Segmentation, Segment Size, and Expected Consumer Utility of Purchasing Products A and B

Segment				Segment number	Segment size	(Expected) Net utility of buying A	(Expected) Net utility of buying B
Tried product	Untried product	Like tried product?	Review signal on untried product				
A	B	Yes	Positive	1	$aP_+/2$	$v - p_n^A$	$X_+ v - p_n^B - t$
			Negative	2	$aP_-/2$	$v - p_n^A$	$X_- v - p_n^B - t$
		No	Positive	3	$(1-a)P_+/2$	$0 - p_n^A$	$X_+ v - p_n^B - t$
			Negative	4	$(1-a)P_-/2$	$0 - p_n^A$	$X_- v - p_n^B - t$
B	A	Yes	Positive	5	$aP_+/2$	$X_+ v - p_n^A - t$	$v - p_n^B$
			Negative	6	$aP_-/2$	$X_- v - p_n^A - t$	$v - p_n^B$
		No	Positive	7	$(1-a)P_+/2$	$X_+ v - p_n^A - t$	$0 - p_n^B$
			Negative	8	$(1-a)P_-/2$	$X_- v - p_n^A - t$	$0 - p_n^B$

Impact of Product Reviews on Firm Profitability

To examine the impact of product reviews on firm profitability, we first derive each firm's demand and profit function. In each period, the consumers who arrive in this period make a decision to buy the same product they used before, buy the other untried product, or buy neither product. A consumer will choose the same product that he or she tried before only if the product provides a utility greater than (or equal to) the expected utility of switching to the untried product and the surplus received from the purchase is nonnegative. For example, for a consumer in segment 1 in Table 2, he or she will choose product A again if $v - p_n^A \geq X_+ v - p_n^B - t$ and $v - p_n^A \geq 0$, choose product B if $v - p_n^A < X_+ v - p_n^B - t$ and $X_+ v - p_n^B - t \geq 0$, or choose neither product if $v - p_n^A < 0$ and $X_+ v - p_n^B - t < 0$. Repeating this analysis for all the other segments described in Table 2 and combining all the segments purchasing from firm j for each pair of p_n^A and p_n^B yields the following demand for firm j's product in period n (denoted as D_n^j):

$$
D_n^j = \begin{cases}
0 & \text{if } p_n^j > p_n^k + (1 - X_-)v + t \text{ and } X_+ v - t < p_n^j \leq v \\[2mm]
\dfrac{aP_-}{2} & \text{if } p_n^k + (1 - X_+)v + t < p_n^j \leq p_n^k + (1 - X_-)v + t \text{ and} \\[1mm]
& X_+ v - t < p_n^j \leq v \\[2mm]
\dfrac{a}{2} & \text{if } 0 \leq p_n^j \leq p_n^k + (1 - X_+)v + t \text{ and } X_+ v - t < p_n^j \leq v \\[2mm]
\dfrac{(1-a)P_+}{2} & \text{if } p_n^j > p_n^k + (1 - X_-)v + t \text{ and } X_- v - t < p_n^j \leq X_+ v - t \\[2mm]
\dfrac{(1-a)P_+ + aP_-}{2} & \text{if } p_n^k + (1 - X_+)v + t < p_n^j \leq p_n^k + (1 - X_-)v + t \text{ and} \\[1mm]
& X_- v - t < p_n^j \leq X_+ v - t \\[2mm]
\dfrac{a + (1-a)P_+}{2} & \text{if } p_n^k - (1 - X_+)v - t < p_n^j \leq p_n^k + (1 - X_+)v + t \\[1mm]
& \text{and } X_- v - t < p_n^j \leq X_+ v - t \\[2mm]
\dfrac{a + P_+}{2} & \text{if } 0 \leq p_n^j \leq p_n^k - (1 - X_+)v - t \text{ and} \\[1mm]
& X_- v - t < p_n^j \leq X_+ v - t \\[2mm]
\dfrac{1-a}{2} & \text{if } p_n^j > p_n^k + (1 - X_-)v + t \text{ and } p_n^j \leq X_- v - t \\[2mm]
\dfrac{aP_- + 1 - a}{2} & \text{if } p_n^k + (1 - X_+)v + t < p_n^j \leq p_n^k + (1 - X_-)v + t \text{ and} \\[1mm]
& p_n^j \leq X_- v - t \\[2mm]
\dfrac{1}{2} & \text{if } p_n^k - (1 - X_+)v - t < p_n^j \leq p_n^k + (1 - X_+)v + t \text{ and} \\[1mm]
& p_n^j \leq X_- v - t \\[2mm]
\dfrac{1 + aP_+}{2} & \text{if } p_n^k - (1 - X_-)v - t < p_n^j \leq p_n^k - (1 - X_+)v - t \text{ and} \\[1mm]
& p_n^j \leq X_- v - t \\[2mm]
\dfrac{1 + a}{2} & \text{if } 0 \leq p_n^j \leq p_n^k - (1 - X_-)v - t \text{ and } p_n^j \leq X_- v - t,
\end{cases}
$$

where $j, k \in \{A, B\}$ and $k \neq j$. Firm j's profit in period n is $\pi_n^j = p_n^j D_n^j$. Each firm selects the optimal price in each period to optimize its intertemporal profit $\sum_{s=0}^{\infty} \delta^s \pi_{n+s}^j$, taking into account its competitor's reaction in future periods.

The equilibrium of our price competition game under this demand structure is presented in Result 1. Our results suggest that the profit-maximizing equilibrium price is symmetric across firms and constant over time (i.e., $p_n^A = p_n^B = p$, where p is a price independent of n). As shown in Appendix A, any other equilibrium, if it exists, is less profitable. The equilibrium is derived under the condition $t/v \geq 1/4$ to preserve tractability (see Appendix A). Thus, we focus on a setting where the explicit switching cost (i.e., the switching cost unrelated to consumer informedness) is significant and firms can effectively use price to improve customer retention. This condition leaves out markets that are extremely competitive irrespective of information conditions; that is, we derive our results for the region where review informativeness can play a substantial role in competition. In Appendix Figure A1, we present the results for two numerical examples in the other parameter region ($t/v < 1/4$), which further confirm that our results are not limited to the selected parameter region.

Result 1: When product value is uncertain to consumers before purchase, the explicit switching cost (unrelated to consumer informedness) is nonnegligible ($t/v \geq 1/4$), and reviews are available with different informativeness ($1/2 \leq \theta \leq 1$); equilibrium prices, demands, and profits can be described as follows:

$$
p_n^j = \begin{cases} v & \text{if } \dfrac{t}{v} \geq T_1 \\[2ex] T_P & \text{if } T_2 < \dfrac{t}{v} < T_1 \\[2ex] X_+ v - t & \text{if } \dfrac{t}{v} \leq T_2 \end{cases}
$$

$$
D_n^j = \begin{cases} \dfrac{a}{2} & \text{if } \dfrac{t}{v} > T_2 \\[2ex] \dfrac{a}{2} + \dfrac{(1-a)P_+}{2} & \text{if } \dfrac{t}{v} \leq T_2 \end{cases}
$$

$$
\pi_n^j = \begin{cases} \dfrac{av}{2} & \text{if } \dfrac{t}{v} \geq T_1 \\[2ex] \dfrac{aT_P}{2} & \text{if } T_2 < \dfrac{t}{v} < T_1 \\[2ex] \dfrac{(X_+ v - t)(a + (1-a)P_+)}{2} & \text{if } \dfrac{t}{v} \leq T_2, \end{cases}
$$

where

$$T_1 = \text{Max}\left\{ X_+ - \frac{2a}{a(2-P_+)+2P_+}, X_- - \frac{2a}{2+a} \right\}$$

$$T_2 = X_+ - \frac{a(a(2-P_+)+2P_+)}{a(4-3P_+)P_+ + 2P_+^2 + a^2(2-(2-P_+)P_+)},$$

and

$$X_+ v - t < T_P < v.$$

See Appendix A for the proof of Result 1 and the functional form for T_P (omitted here due to its complexity).

Result 1 suggests that if the explicit switching cost is high ($t/v > T_2$), each firm charges either v or T_P (a price lower than v) to target only its own satisfied customers: firm A targets segments 1 and 2 and firm B targets segments 5 and 6. If the explicit switching cost is low ($t/v \leq T_2$), each firm lowers its price to $X_+ v - t$ to attract additionally unsatisfied customers of the competing firm who have not tried their product but receive a positive signal from reviews: firm A attracts segment 7 (unsatisfied customers of firm B who receive a positive signal for firm A) in addition to segments 1 and 2, and firm B attracts segment 3 in addition to segments 5 and 6. Figure 1 graphically depicts the relationship between the ratio of explicit switching cost and product value (t/v) and equilibrium price presented in Result 1 for four examples: $\theta = 0.5$ (completely uninformative reviews), $\theta = 0.7$ (low-informativeness reviews), $\theta = 0.9$ (high-informativeness reviews), and $\theta = 1$ (perfectly informative reviews).

The rationale behind Result 1 can be explained as follows. If each firm targets only its own satisfied consumers (segments 1 and 2 for firm A; segments 5 and 6 for firm B), it can charge a high price due to their uncertainty-driven loyalty and explicit switching costs. If one firm, say, firm A, lowers its price, it has two offsetting effects—it expands demand by capturing the customers of firm B (segments 5 and 7), but loses profits by discounting to loyal customers (segments 1 and 2). When the explicit switching cost is large, the discount needed to attract new customers is so large that the revenue gain from additional customers is more than offset by the revenue loss to existing customers (this corresponds to $t/v \geq T_1$, the white regions in Figure 1). When the explicit switching cost is in the middle range ($T_2 < t/v < T_1$), both firms still target only their returning loyal consumers but have to charge a lower price to defend their existing customer base ($T_P < v$). When the explicit switching cost is low ($t/v \leq T_2$), the revenue gain from expanding demand is higher than the revenue loss from the loyal segments, and both firms lower their price to attract the unsatisfied consumers of the competing firm who receive a "matched" signal from the reviews of the untried product.

The positions of the thresholds, T_1 and T_2, vary with review informativeness (θ). As shown in Figure 1, near the boundaries we have the intuitive results that low-informativeness reviews ($\theta = 0.7$) affect behavior similarly to completely uninformative reviews ($\theta = 0.5$) and high-informativeness reviews ($\theta = 0.9$) are similar to perfectly
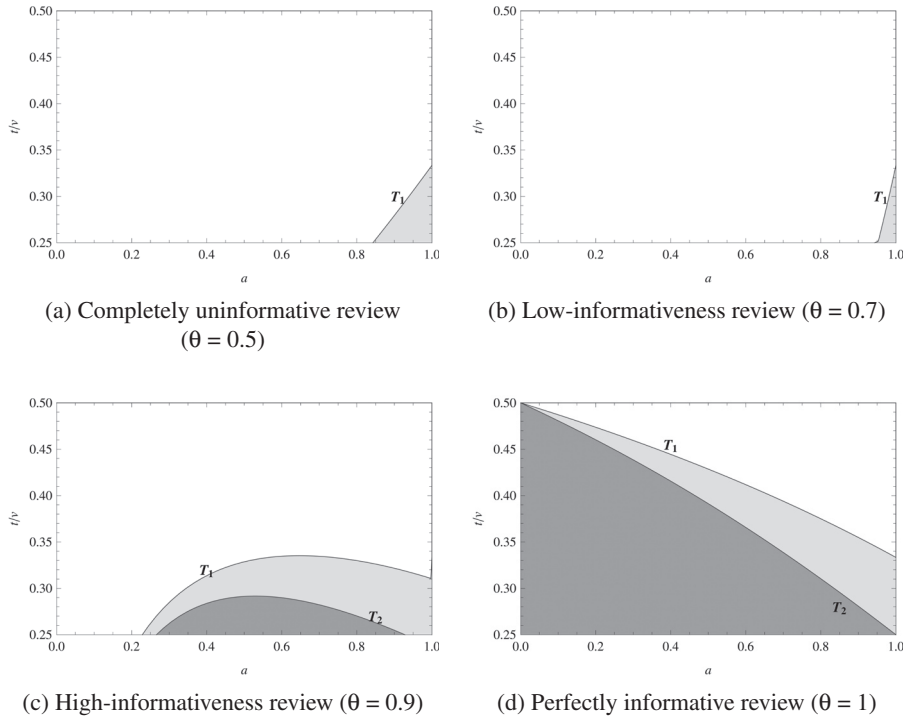
Figure 1. Graphical Presentation of Price Equilibrium Under Different Levels of Review Informativeness (Under Condition $t/v \geq 1/4$)

Notes: White areas: $p_n^j = v$, $D_n^j = a/2$, $\pi_n^j = av/2$; segments 1 and 2 buy from firm A, segments 5 and 6 buy from firm B, the other segments buy from neither firm. Light gray areas: $p_n^j = T_P$, $D_n^j = a/2$, $\pi_n^j = aT_P/2$; segments 1 and 2 buy from firm A, segments 5 and 6 buy from firm B, the other segments buy from neither firm. Dark gray areas: $p_n^j = X_+v - t$, $D_n^j = a/2 + (1 - a)P_+/2$, $\pi_n^j = (X_+v - t)(a + (1 - a)P_+)/2$; segments 1, 2, and 7 buy from firm A, segments 3, 5, and 6 buy from firm B, the other segments buy from neither firm.

informative reviews ($\theta = 1$). However, surprisingly, as θ increases from 0.5 (completely uninformative) to 1 (perfectly informative), the change in the threshold function T_1 is not monotonic. The shape of this relationship is moderated by the potential market size of each product. To illustrate, we depict the relationship between firm profitability and review informativeness for three representative types of products—one for niche products ($a = 0.4$, Figure 2a), one for middle-range products ($a = 0.75$, Figure 2b), and another for mass-market products ($a = 0.9$, Figure 2c). In all three cases, we observe the nonmonotonic change in firm profit as review informativeness changes: firm profit is in an S-shaped relationship with review informativeness. Figure 2 is created using $t/v = 1/4$, but as we show later, similar patterns are observed for other values of t/v.

The rationale behind the nonmonotonic pattern can be explained as follows. Increasing review informativeness exerts three conflicting effects on firm profitability. First, it reduces the value uncertainty of the untried product and increases the willingness to pay of the consumers and thus has the potential to expand firm demand and increase
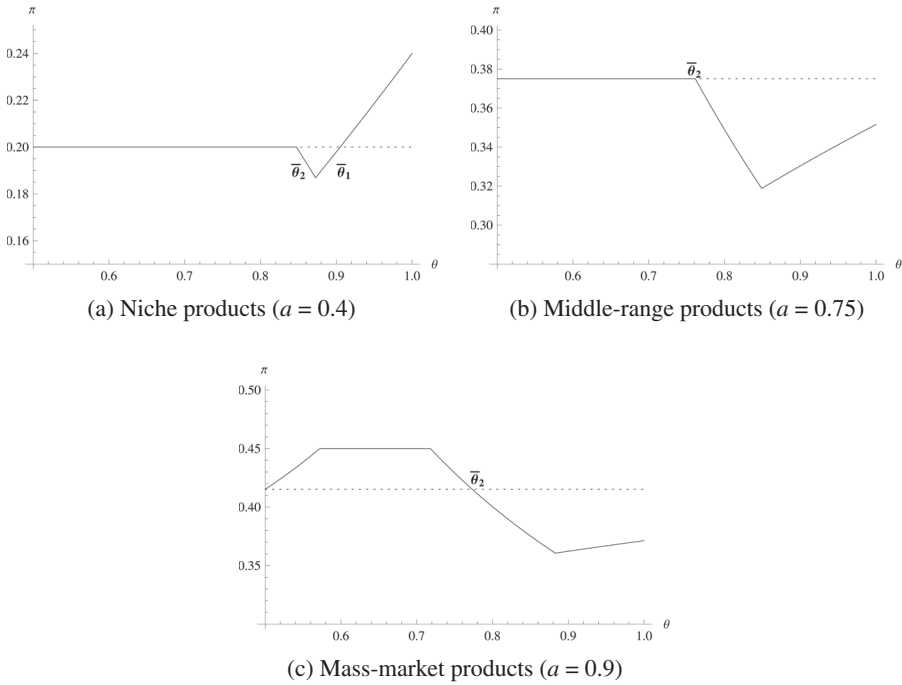
(a) Niche products ($a = 0.4$)

(b) Middle-range products ($a = 0.75$)

(c) Mass-market products ($a = 0.9$)

Figure 2. Firm Profit in Each Period Is in an S-Shaped Relationship with Review Informativeness for the Example of $t/v = 1/4$

firm profit *(demand enhancement)*. For example, as review informativeness θ increases, firm A can target segments 5 and 7 with a higher price (because X_+ increases with θ). Second, if consumers get positive signals from the reviews on the untried product, an increase in review informativeness provides information that enables consumers to learn and switch to the untried product, and hence it may decrease consumers' loyalty to the product they have tried before and lower the loyalty premium that firms can charge to returning consumers *(switching risk reduction)*. For example, for the consumers in segment 1, the relative willingness to pay for product A versus product B is lowered as θ increases, and so firm A may be forced to lower the price to prevent these consumers from switching. Third, if consumers get negative signals from the reviews on the untried product, an increase in review informativeness enlarges the gap between the willingness to pay for the tried product versus that for the untried product. This increased gap reduces the likelihood of these consumers responding to a price cut offered on the untried product, and thus reinforces the firm's ability to charge a loyalty premium *(switching benefit reduction)*. For example, for the consumers in segment 2, as θ increases, poor-quality reviews increase the relative willingness to pay for product A versus product B, so firm A has less of a need to compete through a lower price to retain its existing customers and firm B has less an incentive to try to capture them.

The ultimate impact of an increase in review informativeness on firm profitability is thus contingent on the relative strength of these three conflicting effects, which further

depends on the magnitude of review informativeness θ and the potential market size a. If review informativeness is low, an initial increase in review informativeness has a larger impact on the *switching benefit reduction* effect, potentially leading to higher profit. Whether it leads to an actual profit increase depends on whether there is an opportunity for a profitable price increase, which in turn depends on the potential market size of each product. If a is small, the untried product is likely to be an "unmatched" product for most consumers; hence, without reviews, the consumers' incentive to switch is low. Thus, firms are able to charge v (the highest possible price to charge) when no reviews are available, and so the *switching benefit reduction* effect cannot further increase price and profit. This explains the flat region in Figures 2a and 2b where an increase in review informativeness initially does not change firm profit. However, if a is large, the likelihood of the untried product matching a consumer's preference is high. Both firms have to charge a price lower than v to defend their own customers when review informativeness is low. Thus, as a result of the *switching benefit reduction* effect, an increase in review informativeness enables the firms to increase the price and earn higher profits until the price reaches v. This explains the profit increase in Figure 2c. As review informativeness further increases, for all a, product uncertainty is gradually resolved and the customers increasingly consider switching products; that is, the *switching risk reduction* effect will start to dominate, causing firm profit to decrease. Eventually, all the consumers find their preferred product as reviews become close to being perfectly informative, and most of the effect is in the expansion of demand (*demand enhancement* effect). Thus, the interplay of these three conflicting effects overall gives rise to an S-shaped relationship between review informativeness and firm profit.

While the S-shaped relationship is common for products of all potential market sizes (a), the value of a determines whether firm profit eventually is higher under perfect information (or highly informative reviews) than under no information (i.e., completely uninformative reviews); that is, while a rising curve is observed at high values of θ for all values of a in Figure 2, it eventually crosses the profit level in the absence of reviews (the dotted line) only for the niche products in Figure 2a. This is because product fit matters most for niche products. Not only are consumers more willing to pay for a product that fits compared to a product with uncertain value, the firms are also more likely to be sufficiently differentiated so that they can extract almost all of this additional fit benefit, which is not possible, however, for mass-market products because of intensified competition in the large overlapped consumer segment for which the two firms compete under a large a. Thus, firms generally prefer informative reviews for niche products.

The relationships described above are affected by the explicit switching cost t (i.e., the switching cost unrelated to consumer informedness). When the explicit switching cost is sufficiently low ($1/4 \leq t/v \leq 1/3$), then the effects described earlier prevail. When the explicit switching cost is high ($t/v \geq 1/3$), the region where the *switching benefit reduction* effect increases profits for mass-market products (higher a) as review informativeness increases (similar to Figure 2c) is eliminated because the explicit switching cost provides an effective barrier to price competition. In this case, for all

a, when reviews are not available, switching is not a concern and both firms already charge *v*, and therefore the *switching benefit reduction* effect cannot further improve firm profit. These relationships are depicted in Figures 3a and 3b for two representative values of t/v, 0.25 (low) and 0.35 (high). These results are also summarized in Result 2 (see Appendix B for the derivation of these results).

Result 2: Effects of consumer reviews of different informativeness on firm profitability relative to the scenario of no reviews (under condition $t/v \geq 1/4$)

Market Condition	Impact of Reviews with Different Informativeness $(1/2 \leq \theta \leq 1)$
Niche products $a < \bar{a}_1$	Low-informativeness reviews $(1/2 \leq \theta \leq \bar{\theta}_2)$ do not affect profit
	High-informativeness reviews $(\bar{\theta}_2 < \theta < \bar{\theta}_1)$ lead to lower profit
	Extremely high-informativeness reviews $(\bar{\theta}_1 < \theta \leq 1)$ lead to higher profit
Middle-range products $\bar{a}_1 < a < \bar{a}_2$	Low-informativeness reviews $(1/2 \leq \theta \leq \bar{\theta}_2)$ do not affect profit
	High-informativeness reviews $(\bar{\theta}_2 < \theta \leq 1)$ lead to lower profit
Mass-market products $a > \bar{a}_2$	
Low switching cost $t/v < 1/3$	Low-informativeness reviews $(1/2 \leq \theta < \bar{\theta}_2)$ lead to higher profit
	High-informativeness reviews $(\bar{\theta}_2 < \theta \leq 1)$ lead to lower profit
High switching cost $t/v \geq 1/3$	Reviews do not affect profit

$$\bar{a}_1 = \frac{v - 2t}{v - t}$$

and

$$\bar{a}_2 = \mathrm{Min}\left\{\frac{2(v - 2t)}{v - t}, \; \frac{t + \sqrt{t^2 + 8tv}}{2v}\right\}.$$

See Appendix B for threshold values $\bar{\theta}_1$ and $\bar{\theta}_2$.

Consistent with our earlier discussion on Figure 2, two results are evident from Figure 3 and Result 2. First, imperfect information provided through reviews can increase, decrease, or have no effect on firm profit compared to the scenario with no reviews. Second, as the informativeness of reviews increases, the impact of reviews on firm profit relative to the scenario of no reviews changes nonmonotonically and can be either higher or lower than under full information. For example, in Figure 3a, for the case
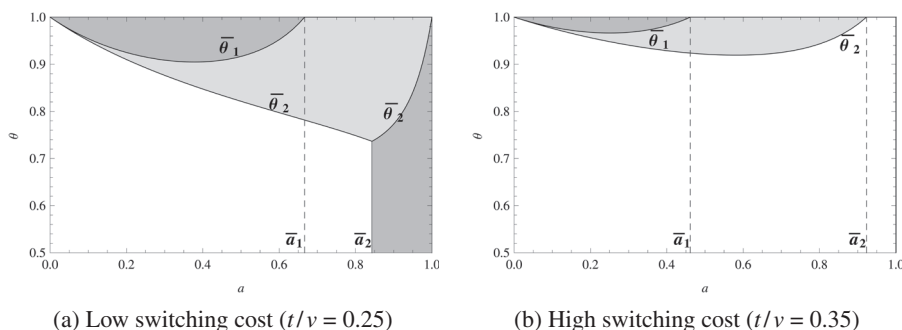
(a) Low switching cost ($t/v = 0.25$)   (b) High switching cost ($t/v = 0.35$)

Figure 3. Effects of Consumer Reviews on Firm Profitability Compared to the No-Review Scenario for Different Values of a and θ for Two Representative Examples: $t/v = 0.25$ and $t/v = 0.35$

Notes: Results are similar for other values of t/v: the low switching cost case ($1/4 \le t/v < 1/3$) is similar to Figure 3a and the high switching cost case ($t/v \ge 1/3$) is similar to Figure 3b. White areas: reviews do not affect firm profit. Light gray areas: reviews lead to lower firm profit compared to the no-reviews scenario. Dark gray areas: reviews lead to higher firm profit compared to the no-reviews scenario.

of $a = 0.4$ (niche products), perfect information ($\theta = 1$) leads to higher firm profit, but lower-informativeness reviews ($\theta < \bar{\theta}_1$) either lead to lower firm profit or do not affect firm profit, compared to the no-reviews scenario; for the case of $a = 0.9$ (mass-market products with a low switching cost), perfect information ($\theta = 1$) decreases firm profit, but low-informativeness reviews ($\theta < \bar{\theta}_2$) increase profit compared to the no-reviews scenario. If we draw a graph for a particular value of a and t/v ($t/v \ge 1/4$), we observe a similar S-shaped relationship between firm profit and review informativeness as shown in Figure 2, except in the region of $a > \bar{a}_2$ and $t/v \ge 1/3$, where reviews do not affect profit. Thus, we have the following proposition:

> *Proposition (Review Informativeness and Firm Profitability):[4] The profits of competing firms with installed customer bases and repeat purchase products are either not affected by reviews or have an S-shaped relationship with review informativeness, suggesting a nonmonotonic impact of review informativeness on firm profitability.*

The nonmonotonic effect of reviews on firm profitability suggests that there may exist an "interior" optimal level of consumer informedness that is neither fully informed nor completely uninformed. According to Figures 2 and 3, this nonlinear relationship varies for different types of products and therefore suggests product-specific implications for firms' policy on facilitating consumer reviews.

For niche products (see Figure 2a and Figure 3 where $a < \bar{a}_1$), firms make the highest profit if the consumers are fully informed. In those markets, because of the strong *demand enhancement* effect, highly informative product information can enable firms to reach consumers whom they were not able to reach otherwise without risking a price war. Therefore, firms should make every effort to encourage informative reviews. This encouragement is especially important if the informativeness of reviews falls in the

region of $\bar{\theta}_2 < \theta < \bar{\theta}_1$ because firms make the lowest profit in this case (lower than both the no-reviews and the perfect-information scenarios) due to *switching risk reduction.* For mass-market products (see Figures 2c and 3a where $a > \bar{a}_2$), however, the highest profit is "interior," achieved at a level of consumer information that is neither fully uninformed nor fully informed. For those products, due to the expected *switching benefit reduction,* a modest amount of product information (low-informativeness reviews with $\theta < \bar{\theta}_2$) available to the consumers further enlarges the difference between the value of the tried product and the expected value of the untried product for the consumers likely responding to competitive price undercutting. This increased information advantage enables the firms to charge a higher price. This effect, however, can be reversed if the amount of product information exceeds a certain threshold ($\theta > \bar{\theta}_2$). Correspondingly, firms should facilitate reviews for those products only if the informativeness of reviews is within the optimal range ($\theta < \bar{\theta}_2$). For middle-range products (see Figures 2b and 3 where $\bar{a}_1 < a < \bar{a}_2$), reviews with low informativeness ($\theta < \bar{\theta}_2$) are not powerful enough to change the dynamics of competition (as discussed before, *switching benefit reduction* does not increase profit in this case because both firms already charge price v when no reviews are available). Highly informative reviews ($\theta > \bar{\theta}_2$), however, have the potential to lower firm profit due to *switching risk reduction.* As discussed before, the diverging effects of highly informative reviews on niche products (small a) versus popular products (large a) are driven by the firms' inability to extract all the *demand enhancement* benefit to entirely offset the *switching risk reduction* effect due to intensified firm competition in the overlapped consumer segment for which the two firms compete under large a.

These results are derived for the setting where the explicit switching cost is non-negligible ($t/v \geq 1/4$). Appendix Figure A1 shows numerical results for the setting where this condition does not hold ($t/v = 0.1$) and shows that our basic conclusion that maximal profits are achieved at the intermediate levels of informativeness for mass-market products is not sensitive to this tractability assumption. Our result that imperfect information lowers profits for niche products also holds. Thus, we have the following corollary:

> *Corollary 1 (Optimal Review Informativeness from the Firms' Perspective): The optimal level of consumer informedness from the firms' perspective varies by product and need not be at the boundary (full informativeness or full uninformativeness). Firms generally prefer high consumer informedness for niche products but low consumer informedness for mass-market products.*

Impact of Consumer Reviews on Consumer Surplus

From the consumers' point of view, competition can benefit consumers by lowering prices. As a result, if reviews with low informativeness can relax competition and increase firms' profits, they may hurt consumer surplus, even if consumers know the informativeness of reviews (θ) and make fully rational decisions.[5] This result complements previous findings that review bias (uninformative reviews due to heterogeneity

of preferences) can hurt consumer surplus if the consumers are not aware of the bias or do not have enough information to correct the bias [24]. On the other hand, if the informativeness of reviews is high, firms receive lower profits due to increased competition but consumer surplus may be increased. From this perspective, the impact of consumer reviews on consumer surplus is mainly opposite to the impact of consumer reviews on firm profitability. There is one exception, however; when a is small ($a < \bar{a}_1$) and reviews are extremely informative ($\theta > \bar{\theta}_1$), both firm profit and consumer surplus are increased as a result of reviews. This exception arises because in that region, the firms make higher profits due to expanded demand (targeting additionally the unsatisfied consumers of the competing firm) and the consumers benefit from lowered prices driven by intensified competition. Thus, highly accurate reviews in markets for niche products can be especially beneficial, enabling the customers to find a product that fits their preferences and enabling the firms to sell highly differentiated products and still capture a significant portion of the value created. Results about the impact of consumer reviews on consumer surplus are summarized in Result 3:

Result 3: Effects of consumer reviews of different informativeness on consumer surplus relative to the scenario of no reviews (under condition $t/v \geq 1/4$)

Market Condition	Impact of Reviews with Different Informativeness ($1/2 \leq \theta \leq 1$)
Niche products or middle-range products $a < \bar{a}_2$	Low-informativeness reviews ($1/2 \leq \theta \leq \bar{\theta}_2$) do not affect consumer surplus
	High-informativeness reviews ($\bar{\theta}_2 < \theta \leq 1$) lead to higher consumer surplus
Mass-market products $a > \bar{a}_2$	
Low switching cost $t/v < 1/3$	Low-informativeness reviews ($1/2 \leq \theta < \bar{\theta}_2$) lead to lower consumer surplus
	High-informativeness reviews ($\bar{\theta}_2 < \theta \leq 1$) lead to higher consumer surplus
High switching cost $t/v \geq 1/3$	Reviews do not affect consumer surplus

As review informativeness increases, consumer surplus also shows a nonmonotonic behavior. To illustrate, we depict the relationship between consumer surplus and review informativeness for three representative types of products in Figure 4. Because firm profitability and consumer surplus respond to price competition in an opposite manner, Figures 2 and 4 generally show opposite trends as review informativeness increases. For example, in Figure 2a, as review informativeness increases, firm profit first keeps constant, then decreases, and finally increases, whereas in Figure 4a, as review informativeness increases, consumer surplus first keeps constant, then increases, and finally decreases. There is a noticeable difference in Figure 4 that a discontinuous jump occurs when review informativeness increases beyond a certain threshold in all three graphs. That threshold is the level of review informativeness at which the
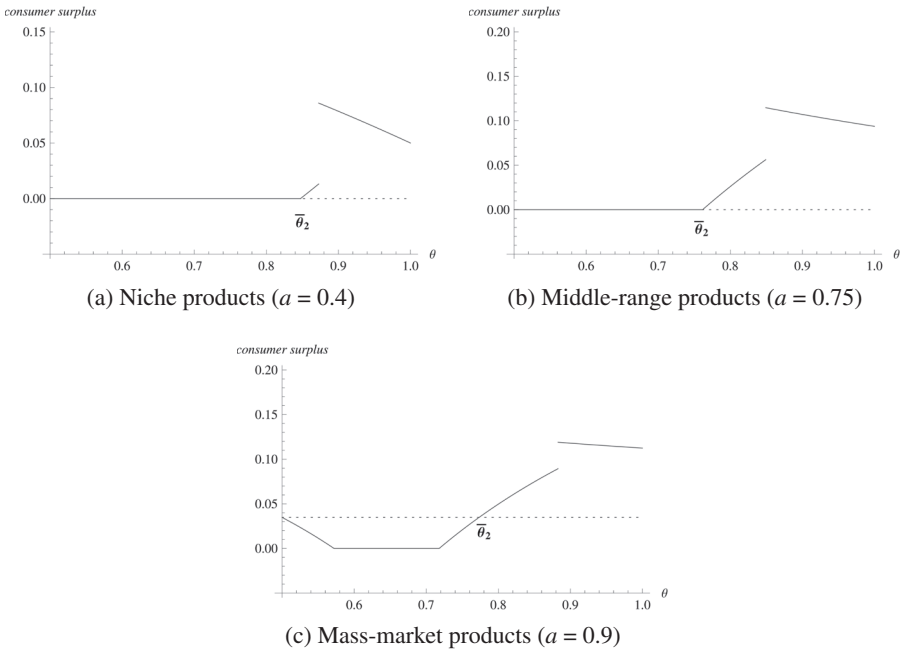
consumer surplus

(a) Niche products ($a = 0.4$)

consumer surplus

(b) Middle-range products ($a = 0.75$)

consumer surplus

(c) Mass-market products ($a = 0.9$)

Figure 4. Consumer Surplus in Each Period Is in an S-Shaped Relationship with Review Informativeness for the Example of $t/v = 1/4$

firms make equal profits by targeting only their own satisfied customers or by targeting additionally the unsatisfied consumers of the competing firm. Beyond that point, because both firms additionally target the unsatisfied consumers of the competing firm, considerably more consumers are served, yielding a significant increase in consumer surplus. Then as review informativeness continues to increase, the firms are able to charge higher prices without losing demand as a result of the dominant *demand enhancement* effect as discussed in the previous section for Figure 2. This explains why, beyond that point, as review informativeness increases, firm profits increase but consumer surplus decreases.

According to Figure 4, consumer surplus is highest when the level of review informativeness is just above the point where firms start to target the unsatisfied consumers of the competing firm. At that point, the consumers are neither fully informed nor completely uninformed; that is, even though consumers are generally better off with high-informativeness reviews (compared to the no-review scenario), full informativeness does not necessarily lead to highest consumer surplus given firms' strategic pricing. Thus, according to Result 3 and Figure 4, we can develop the following corollary:

> *Corollary 2 (Review Informativeness and Consumer Surplus): The optimal level of consumer informedness from the consumers' perspective varies by product and need not be at the boundary (full informativeness). Consumers generally benefit from high-informativeness reviews but not low-informativeness reviews.*

Conclusions and Discussion

WHILE PRODUCT QUALITY UNCERTAINTY CAN ALLOW firms to charge high prices to returning customers for repeat purchase products, uncertainty reduction caused by experience sharing among consumers does not necessarily encourage price competition and lower firm profit. For incumbent firms that sell competing repeat purchase products, the ultimate impact of consumer reviews depends on the relative strength of three effects that these reviews have on each firm's profit. *Demand enhancement* due to increased information about product fit may attract new buyers outside the current customer base, increasing total industry profits. *Switching risk reduction* due to positive information about untried competing products lowers the uncertainty-related switching cost for the current customers, increasing price competition. *Switching benefit reduction* from negative information about an untried product can solidify a firm's customer base and decrease price competition. These conflicting effects can thus give rise to an S-shaped relationship between review informativeness and firm profits. There is an optimal level of review informativeness from the firms' perspective, and this level can be different in different markets depending on the potential market size of each product and the explicit switching cost. Consumers generally benefit from more informative reviews, although only for niche products are the interests of consumers and the interests of producers aligned. Given firms' strategic pricing, consumers can actually be worse off by having low-informativeness reviews than if they had nothing, or benefit more from less than fully informative reviews than if they were fully informed, as the benefit of being better informed about product attributes under some circumstances can be partially offset by the high prices set by firms due to relaxed competition or enhanced demand.

The principal strategic implications of our results are that firms should recognize the role that review informativeness plays in price competition in devising their pricing and promotion strategies and should consider making investments that affect review informativeness when the level of informativeness deviates from the optimum. Sellers of niche products, both individually and collectively, can benefit from increasing review informativeness, but only if reviews can be highly informative. In niche markets that are not covered by existing specialized review sites, firms could consider partnering with competitors or distributors to develop a specialized review service or to support existing general review sites such as Epinions.com or Amazon.com if existing measures suggest that consumers find these reviews informative. Measurement of consumer informativeness could rely on existing measures already in review facilities (such as "helpfulness votes"; see, e.g., [14]) or direct measurement through surveys or focus groups. Support could take the form of financial support through advertising, or operational support by providing product samples or test equipment to critical reviewers. In some cases, manufacturers could consider offering proprietary reviews on their Web sites (as is the practice of Dell and Sony), although concerns about credibility will likely be stronger in manufacturer-sponsored rather than third-party reviews even if the content is identical. Producers of mass-market products with broad appeal have substantially different incentives, as review informativeness generally shifts surplus

from producers to consumers; firms can expect a robust market for third-party review services and can privately benefit from ensuring that their own products are well positioned, but do not gain from a general increase in consumer informedness. Mass-market firms that have products with contractual or inherent switching costs (e.g., wireless phones for the former and retail banking services for the latter) may be indifferent to reviews. Moreover, third-party sites are less interested in providing reviews in these markets because consumers receive little benefit from reviews.

Our analysis is intended to be largely prescriptive rather than descriptive, and the factors that drive price competition in our models are likely to be highly context specific, making broad empirical study challenging. However, there is evidence that the factors that we identify, such as the strength of idiosyncratic preferences and explicit switching cost, show considerable variation across markets, giving rise to variation in the optimal levels of review informativeness in our model. For instance, our prior discussion already highlights beer, luxury hotels, specialty restaurants, and skin-care products as niche market products for which highly informative reviews can be useful. But soft drinks, Web hosts, online bookstores, and online banking services can be viewed as mass-market products. Some products can be either, depending on the context. Wireless services are mass-market products in well-covered urban areas and niche products in suburban or rural areas where coverage is sparse. The distinction is straightforward: Some markets are such that almost any product could satisfy almost any consumer, whereas other markets are such that the fit between a specific product and a specific consumer is very important. There is also variation in explicit switching costs. Some products we discussed exhibit high switching costs due to complementary product compatibility (skin care), contracts (wireless services), or the actual effort required in switching (banking and Web hosting services), whereas most of the other products (beer, hotels, bookstores) that we describe have low explicit switching costs. Thus, it is clear that the exogenous parameters that drive our results are well defined both theoretically and practically and do show variation in real markets. Moreover, because it is possible to characterize different markets as having different combinations of our exogenous parameters, there is the possibility of empirically validating our predictions by comparing the influence of reviews across different product markets. These empirical tests could be further enhanced if they were done concurrently with an exogenous change in the informativeness of reviews, such as the introduction of a new review service or modifications of existing review services, by moving from single to multidimensional product ratings, introducing reviewer feedback, changing the way reviewer profiles are presented, or providing advanced search features.

We can also find support for our major propositions in existing empirical work on online product reviews. There have been three prior empirical studies considering repeat purchase products, focusing on beer, luxury hotels, and online retailers (bookstores) [9, 10, 20]. In the market for craft beers, retailers report significant improvements in the ability to market highly differentiated and high-priced beers based on reviews provided by RateBeer (www.ratebeer.com), a high-traffic specialty review site dedicated to this market [8]. A notable characteristic of RateBeer is that it emphasizes review accuracy by using technology and social processes to detect fraudulent or uninformed reviews

and providing extensive information on both products and reviewer characteristics [8]. Studies of both beer [10] and luxury hotels [9] have also shown that the consumers in these markets are most responsive to the number and complexity of reviews in the upper and lower ends of the rating distribution, also suggesting the importance of review informativeness in these markets. However, neither of these markets shows evidence that these highly informative reviews have increased price competition [2, 8]. In contrast, prior work has shown that online reviews do facilitate price competition in mass-market products such as online retail [20], and it has been argued that some review sites, such as TripAdvisor (www.tripadvisor.com), play a significant role in encouraging price competition among middle-market hotels (another mass-market product), largely to the benefit of travel sites such as Hotels.com (www.hotels.com) [9]. Finally, our model results are consistent with the observation that niche market products tend to be covered by specialty review sites such as RateBeer for beer, Zagat Survey (www.zagat.com) for restaurants, and MakeupAlley (http://makeupalley.com) for cosmetics, while mass-market products are principally covered by generalist review sites (e.g., Epinions). In addition, generalist review sites often provide limited coverage for niche products if they cover niche products at all. This is consistent with the especially high value of informative reviews for niche products. The economic trade-off between having the broad reach of a generalist review site and having the narrow reach of a specialized site appears to favor specialized sites only for niche markets. Thus, our major propositions are consistent with the institutional structure of online review services.

While we focus specifically on consumer reviews, our results extend to any forum that provides consumer information, such as blogs or third-party reviews.[6] To the extent that all these forums provide greater consumer information, our results provide insight into their effect on competition. However, without studying the relative informativeness of these other media, we cannot determine the extent to which firms should selectively embrace some types of media but not others.

There are also several limitations with our modeling approach that call for future research. There are a few technical assumptions embedded in our model for tractability that could be relaxed. First, under the single-reentry assumption, consumer experimentation is not considered in our model—that is, consumers cannot try both products and pick the one with the better fit. This assumption is common in the literature (e.g., [34]) because it narrows the focus to products for which reviews can play a role, such as when it is costly to experiment or when consumer tastes may change over time. Relaxing the single-reentry assumption provides more opportunities for firms to compete, which should increase the degree of price competition but is unlikely to change the structural characteristics of our results. Similarly, we do not consider the search costs to obtain reviews. Relaxing this assumption would likely lead consumers to be less informed, but retain most of the structure of our results. However, examining search is considerably more interesting if firms can control consumer search costs, as this would add a new dimension of competition.

In addition, while this paper set out to examine the impact of consumer reviews on price competition between firms, we did not examine how firms might respond to online

review sites by changing product design. For instance, can firms alter products to have greater or less complexity to affect review informativeness in a favorable direction? Alternatively, there could also be an important role for quality investment that could create a separate dimension of differentiation in quality as well as fit that could either soften or intensify competition. Finally, field studies in cooperation with industrial partners can also be promising to better understand how our model predictions can be effectively applied in practice.

Notes

1. A similar assumption is used by Maskin and Tirole [25] to model oligopoly competition. We also examined the alternative simultaneous move assumption under which firms choose price at the same time. This alternative assumption may lead to mixed-strategy equilibrium in certain parameter regions, but the model still yields the same qualitative conclusions. Therefore, we are confident that our results presented in this paper are not sensitive to this alternating move assumption.

2. We assume θ is independent of a. While these two parameters can potentially both be affected by product characteristics such as product complexity, they are distinct concepts—both a niche product and a mass-market product can be simple and readily describable in reviews or can be too complex to be reviewed in an informative way. By having a two-dimensional characterization, our model is more general and allows for mapping other concepts of product distinction into this space.

3. If θ is less than 1/2, a consumer is more likely to receive an incorrect signal than a correct one—that is, more than a 50 percent chance a matched consumer will receive an "unmatched" signal and an unmatched consumer will receive a "matched" signal. Knowing this, the consumer will simply interpret a "matched" signal as meaning "unmatched" and vice versa, so that the probability of being signaled correctly $(1 - \theta)$ will be greater than 50 percent. Therefore, the case of θ between 0 and 1/2 is exactly symmetric to the case of θ between 1/2 and 1.

4. Note that support for our main proposition and its associated corollaries relies on analytical results for the region with $t/v \geq 1/4$ and numerical analysis for the remainder of the parameter space.

5. Although low-informativeness reviews may result in a surplus loss for consumers as a group, a consumer still has an individual incentive to read low-informativeness reviews. Reviews always provide some information, so rational consumers will examine reviews before making purchases and benefit by making better purchase decisions for a given set of prices and products. Paradoxically, this seemingly beneficial behavior for individual consumers may result in a higher price paid by all consumers in equilibrium due to decreased competition.

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Appendix A. Proof of Result 1

WE FIRST UTILIZE THE PERFECT-INFORMATION SCENARIO (i.e., reviews are completely informative with $\theta = 1$) to explain in detail how to derive equilibrium and then follow the same procedure to solve equilibrium for the scenario $1/2 \leq \theta < 1$. The equilibrium is first derived assuming that the equilibrium price is symmetric across firms and constant over time. We then show that any other equilibrium, if it exists, is less profitable. Define an indicator function:

$$I_A(x) = \begin{cases} 1 & \text{if } x \in A \\ 0 & \text{if } x \notin A. \end{cases}$$

Scenario of $\theta = 1$

Assume in equilibrium that both firms charge p^* in all periods. Then, according to Table 2, in each period, each firm's profit under $\theta = 1$ is

$$\pi_n^* = \begin{cases} \dfrac{p^* a}{2} & \text{if } p^* > v - t \\ \dfrac{p^* a (2-a)}{2} & \text{if } p^* \leq v - t. \end{cases} \tag{A1}$$

In this analysis, we focus on the parameter regions where the equilibrium price is no lower than $v - t$ under perfect information (i.e., $p^* \geq v - t$). Under this condition, we capture both possibilities in Equation (A1) while preserving tractability. Figure A1 shows numerical results for the setting where this condition does not hold, which shows that our results are not sensitive to this tractability assumption. The equilibrium price maximizes profit taking into account firm reaction in future periods.

A firm may deviate in period n in two ways: undercut its competitor by t to "steal" additional customers (call it "deviation B1") or deviate to a higher price if $p^* < v$ (call it "deviation B2"). We first derive the condition under which one period deviation (deviate in period n and then return to equilibrium price in period $n + 2$) is unprofitable and
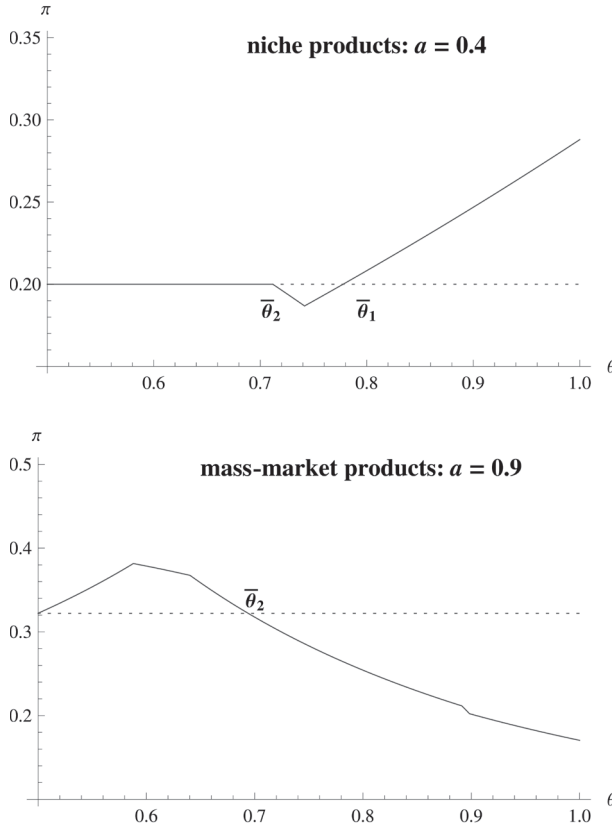
Figure A1. Numerical Demonstration on the Relationship Between Firm Profit in Each Period and Review Informativeness for the Example of $t/v = 0.1$

then illustrate why one period deviation is incentive compatible for the deviating firm. The equilibrium price is derived by maximizing profit while deterring deviation B1. We then show that the derived equilibrium also depresses deviation B2. Without loss of generality, assume that firm B is the deviating firm.

For deviation B1, if firm B undercuts firm A by t (i.e., charges $p^* - t - \varepsilon$, where ε is infinitely close to zero) in period n and returns to p^* in period $n + 2$, then in period $n + 1$, firm A can either continue to charge equilibrium price p^* or lower its price to $p^* - \varepsilon$ to prevent its consumers from switching to firm B. Firm A's profits for these two options are, respectively,

$$
\pi_{n+1}^A = \begin{cases}
\dfrac{p^* \left(2a(1-a) - a(1-a)I_{(v-t,v]}\left(p^*\right)\right)}{2} & \text{if } p_{n+1}^A = p^* \\[4mm]
\dfrac{\left(p^* - \varepsilon\right)\left(a(2-a) - a(1-a)I_{(v-t,v]}\left(p^*\right)\right)}{2} & \text{if } p_{n+1}^A = p^* - \varepsilon.
\end{cases}
$$

Because the latter option provides a higher profit, firm A will lower its price to $p^* - \varepsilon$ in period $n + 1$ and return to p^* in period $n + 3$. Thus, if firm B deviates, it earns $(p^* - t - \varepsilon)a$ in period n, earns

$$\frac{\left(p^* - t - \varepsilon\right)a\left(2 - a\right)}{2}$$

in period $n + 1$, and earns the equilibrium profit

$$\frac{p^*\left(a\left(2 - a\right) - a\left(1 - a\right)I_{(v-t,v]}\left(p^*\right)\right)}{2}$$

in all the periods that follow. Therefore, firm B will not deviate if the following condition holds:

$$\left(p^* - t - \varepsilon\right)a + \frac{\left(p^* - t - \varepsilon\right)a\left(2 - a\right)}{2}\delta \leq \frac{p^*\left(a\left(2 - a\right) - a\left(1 - a\right)I_{(v-t,v]}\left(p^*\right)\right)\left(1 + \delta\right)}{2},$$

which implies (given $\delta = 1$)

$$p^* \leq \frac{\left(4 - a\right)t}{a + 2\left(1 - a\right)I_{(v-t,v]}\left(p^*\right)}. \tag{A2}$$

Under condition (A2), neither firm finds it profitable to undercut the competitor in equilibrium. In addition, if one firm charges a price lower than p^*, the other firm will find it unprofitable to undercut as well. Therefore, it is optimal for firm B to return to the equilibrium price instead of further undercutting firm A in period $n + 2$, because firm A's price is lower than p^* in that period (i.e., one period deviation is incentive compatible for the deviating firm).

Under condition (A2), the equilibrium price that is no lower than $v - t$ and maximizes profit,

$$\frac{p^*\left(a\left(2 - a\right) - a\left(1 - a\right)I_{(v-t,v]}\left(p^*\right)\right)}{2},$$

is

$$p^* = \begin{cases} v & \text{if } \dfrac{t}{v} \geq \dfrac{2 - a}{4 - a} \\[2ex] \dfrac{\left(4 - a\right)t}{2 - a} & \text{if } \dfrac{\left(2 - a\right)^2}{8 - 5a + a^2} < \dfrac{t}{v} < \dfrac{2 - a}{4 - a} \\[2ex] v - t & \text{if } \dfrac{a}{4} \leq \dfrac{t}{v} \leq \dfrac{\left(2 - a\right)^2}{8 - 5a + a^2}. \end{cases} \tag{A3}$$

Thus, the region where the equilibrium price is no lower than $v - t$ for all possible values of a is $t/v \geq 1/4$.

This equilibrium also deters deviation B2. When $p^* = v - t$ (under condition $1/4 \leq t/v \leq (2 - a)^2/(8 - 5a + a^2)$), a firm makes a higher profit in each period by charging p^* than charging any price higher than $v - t$. When $v - t < p^* < v$ (under condition $(2 - a^2)/(8 - 5a + a^2) < t/v < (2 - a)/(4 - a)$), if firm B deviates to a price higher than p^* in period n and returns to p^* in period $n + 2$, firm A makes the highest profit by undercutting firm B by t in period $n + 1$ and returning to p^* in period $n + 3$. Thus, if firm B deviates, it earns at most $av/2$ in period n, $a(1 - a)v/2$ in period $n + 1$, and the equilibrium profit in all the periods that follow, which is less than the total profit it makes if it stays in equilibrium under condition $(2 - a^2)/(8 - 5a + a^2) < t/v < (2 - a)/(4 - a)$. In this case, it is again incentive compatible for firm B to return to the equilibrium price in period $n + 2$—as we just showed, any price higher than p^* in this case leads to lower profit; it is also unprofitable to further undercut firm A provided that firm A's price in that period is lower than p^*, as discussed earlier.

In any other equilibrium, if it exists, the equilibrium price in each period has to satisfy condition (A2). Otherwise, a firm can earn a higher profit by undercutting the competitor by t and returns to that price in the next period. The equilibrium described in condition (A3) produces the highest profit for each firm in each period given in condition (A2) and therefore is the optimal equilibrium.

Scenario of $1/2 \leq \theta < 1$

We now follow the same procedure described in the previous section to derive equilibrium for the scenario of $1/2 \leq \theta < 1$. We assume in equilibrium that both firms charge p^* in all periods. Then, according to Table 2, in each period, each firm's profit is

$$
\pi_n^* = \begin{cases} \dfrac{p^* a}{2} & \text{if } p^* > X_+ v - t \\[2mm] \dfrac{p^*\left(a + (1 - a)P_+\right)}{2} & \text{if } X_- v - t < p^* \leq X_+ v - t \\[2mm] \dfrac{p^*}{2} & \text{if } p^* \leq X_- v - t. \end{cases}
$$

A firm may deviate in period n in two ways: first, undercut its competitor by $v - (X_+ v - t)$ or $v - (X_- v - t)$ to "steal" additional customers; second, deviate to a higher price if $p^* < v$. Similar to the previous section, we can derive the conditions under which the first potential deviation is unprofitable as

$$
p^* \leq \begin{cases} \dfrac{\left(2P_+ + a(2 - P_+)\right)\left((1 - X_+)v + t\right)}{\left(a + 2(1 - a)I_{(X_+ v - t, v]}(p^*)\right)P_+} \\[2mm] \text{if } p^* > (1 - X_+ + X_-)v \\[3mm] \dfrac{\left(2 + aP_+\right)\left((1 - X_+)v + t\right)}{2(1 - a)P_- + aP_+ + 2(1 - a)P_+ I_{(X_+ v - t, v]}(p^*) - 2(1 - a)P_- I_{(0, X_- v - t]}(p_R^*)} \\[2mm] \text{if } p^* \leq (1 - X_+ + X_-)v \end{cases}
$$

and

$$p^* \leq \frac{(2+a)\big((1-X_-)v+t\big)}{2(1-a)P_- + a + 2(1-a)P_+ I_{(X_+v-t,v]}\big(p^*\big) - 2(1-a)P_- I_{(0,X_-v-t]}\big(p^*\big)}.$$

We then can derive the equilibrium price that maximizes profit

$$\frac{p^*\Big(a + (1-a)P_+ - (1-a)P_+ I_{(X_+v-t,v]}\big(p^*\big) + (1-a)P_- I_{(0,X_-v-t]}\big(p^*\big)\Big)}{2}$$

given these conditions and $t/v \geq 1/4$ as

$$p^* = \begin{cases} v & \text{if } \dfrac{t}{v} \geq T_1 \\[2ex] T_P & \text{if } T_2 < \dfrac{t}{v} < T_1 \\[2ex] X_+ v - t & \text{if } \dfrac{t}{v} \leq T_2, \end{cases} \qquad (A4)$$

where

$$T_1 = \text{Max}\left\{ X_+ - \frac{2a}{a(2-P_+)+2P_+}, \ X_- - \frac{2a}{2+a} \right\}$$

$$T_2 = X_+ - \frac{a\big(a(2-P_+)+2P_+\big)}{a(4-3P_+)P_+ + 2P_+^2 + a^2\big(2-(2-P_+)P_+\big)}$$

and

$$T_P = \begin{cases} \text{Min}\left\{ \dfrac{\big(a(2-P_+)+2P_+\big)(v+t-X_+v)}{(2-a)P_+}, \ \dfrac{(a+2)(v+t-X_-v)}{2-a} \right\} \\[2ex] \text{if } \dfrac{t}{v} > \dfrac{(2-a)P_+(2+aP_+)X_- - 2a\big(a(2-P_+)+2P_+\big)(1-X_+)}{4P_+ + 2aP_+(1+P_+) + a^2\big(4-P_+(2+P_+)\big)} \\[2ex] \text{Min}\left\{ \dfrac{(2+aP_+)(v+t-X_+v)}{2-a(2-P_+)}, \ \dfrac{(a+2)(v+t-X_-v)}{2-a} \right\} \\[2ex] \text{if } \dfrac{t}{v} \leq \dfrac{(2-a)P_+(2+aP_+)X_- - 2a\big(a(2-P_+)+2P_+\big)(1-X_+)}{4P_+ + 2aP_+(1+P_+) + a^2\big(4-P_+(2+P_+)\big)}. \end{cases}$$

Following the same logic as described in the previous section, we can also show in this scenario that one period deviation is incentive compatible for the deviating firm, that the equilibrium described in Equation (A4) discourages the second potential deviation, and that any other equilibrium, if it exits, is less profitable.

Appendix B. Derivation of Result 2 (Under Condition $t/v \geq 1/4$)

THE IMPACT OF REVIEWS ON FIRM PROFIT IS DERIVED BY comparing results in Lemma 1 with the scenario where no reviews are available (equivalent to the scenario of $\theta = 1/2$) for different market conditions as follows.

If $t/v < a^2/(2 + a)$ (i.e., $a > (t + (t^2 + 8tv)^{1/2})/2v$), this region appears only if $t/v \leq 1/3$), then according to Lemma 1, in the no-reviews scenario, both firms charge

$$\frac{(2+a)(v+t-av)}{2-a}$$

and earn

$$\frac{a(2+a)(v+t-av)}{4-2a}$$

in each period. If reviews are available, then there exist three possibilities as suggested by Lemma 2. If $t/v \geq T_1$, then firms charge v and earn a higher profit. If $T_2 < t/v < T_1$, then firms charge T_P (between $X_+ v - t$ and v) and earn a higher profit if their per period profit ($T_P a/2$) is higher than

$$\frac{a(2+a)(v+t-av)}{4-2a},$$

which requires that

$$\theta <$$

$$\frac{4 - \frac{2t}{v} + a\left(a\left(4a - 5 - \frac{8t}{v}\right) - 3 + \frac{8t}{v}\right) - \sqrt{(1-a)^2 \, a(16+17a) - \frac{12a(1+a(2a-3))t}{v} + 4\left(\frac{t}{v} - \frac{2at}{v}\right)^2}}{4(2a-1)\left(a^2 - 1 + \frac{t}{v} - \frac{2at}{v}\right)}.$$

If $t/v \leq T_2$, then firms charge $X_+ v - t$ and earn less profit than in the no-reviews scenario. Denote η_1 as

$$\frac{4 - \frac{2t}{v} + a\left(a\left(4a - 5 - \frac{8t}{v}\right) - 3 + \frac{8t}{v}\right) - \sqrt{(1-a)^2 \, a(16+17a) - \frac{12a(1+a(2a-3))t}{v} + 4\left(\frac{t}{v} - \frac{2at}{v}\right)^2}}{4(2a-1)\left(a^2 - 1 + \frac{t}{v} - \frac{2at}{v}\right)}.$$

Then in this region, reviews increase profit if $\theta < \eta_1$ and decrease profit otherwise.

If $t/v > a^2/(2 + a)$ (i.e., $a < (t + (t^2 + 8tv)^{1/2})/2v$), according to Lemma 1, in the no-reviews scenario, both firms charge v and earn $av/2$ in each period. If reviews are available, then according to Lemma 2, there are three possibilities. If $t/v \geq T_1$, then firms charge v and earn the same profit. If $T_2 < t/v < T_1$, then firms charge T_P (between $X_+ v - t$ and v) and earn less profit. If $t/v \leq T_2$, then firms charge $X_+ v - t$ and earn higher profit if

$$\frac{(X_+ v - t)(a + (1-a)P_+)}{2}$$

is higher than $av/2$, which requires that

$$\theta <$$

$$\frac{a\left(\frac{7t}{v} - 2 + a\left(3 - a + \frac{4(a-2)t}{v}\right) + \sqrt{(1-a)^2 a(4+a) + \frac{2(2 + a((7-2a)a - 7))t}{v} + \left(\frac{t}{v} - \frac{2at}{v}\right)^2}\right) - \frac{2t}{v}}{2(1 + a(2a-3))\left(a\left(\frac{2t}{v} - 1\right) - \frac{t}{v}\right)}.$$

Solving $t/v \geq T_1$ suggests that

$$\theta \leq$$

$$\frac{a\left(\frac{12t}{v} - 4 + a\left(5 - \frac{10t}{v} + a\left(\frac{4t}{v} - 1\right)\right) + \sqrt{(a-1)a(a(7+a) - 16) + \frac{16t}{v} - \frac{4a(13 + a(2a-11))t}{v} + 4\left(\frac{t}{v} - \frac{2at}{v}\right)^2}\right) - \frac{4t}{v}}{2(2 + a(2a-5))\left(a\left(\frac{2t}{v} - 1\right) - \frac{t}{v}\right)}.$$

Denote $\bar{\theta}_1$ as

$$\frac{a\left(\frac{7t}{v} - 2 + a\left(3 - a + \frac{4(a-2)t}{v}\right) + \sqrt{(1-a)^2 a(4+a) + \frac{2(2 + a((7-2a)a - 7))t}{v} + \left(\frac{t}{v} - \frac{2at}{v}\right)^2}\right) - \frac{2t}{v}}{2(1 + a(2a-3))\left(a\left(\frac{2t}{v} - 1\right) - \frac{t}{v}\right)}$$

and η_2 as

$$\frac{a\left(\frac{12t}{v} - 4 + a\left(5 - \frac{10t}{v} + a\left(\frac{4t}{v} - 1\right)\right) + \sqrt{(a-1)a(a(7+a) - 16) + \frac{16t}{v} - \frac{4a(13 + a(2a-11))t}{v} + 4\left(\frac{t}{v} - \frac{2at}{v}\right)^2}\right) - \frac{4t}{v}}{2(2 + a(2a-5))\left(a\left(\frac{2t}{v} - 1\right) - \frac{t}{v}\right)}.$$

Then in this region, reviews increase profit if $\theta > \bar{\theta}_1$, decrease profit if $\eta_2 < \theta < \bar{\theta}_1$, and do not affect profit if $\theta \leq \eta_2$.

Define $\bar{\theta}_2$ as $\text{Max}\{\eta_1, \eta_2\}$. $\bar{\theta}_1$ is higher than 1 if a is higher than $(v - 2t)/(v - t)$, which is smaller than $(t + (t^2 + 8tv)^{1/2})/2v$. $\bar{\theta}_2$ is higher than 1 if a is higher than $2(v - 2t)/(v - t)$, which is smaller than $(t + (t^2 + 8tv)^{1/2})/2v$ if $t/v > 1/3$. These conditions determine whether the aforementioned regions of θ appear for different values of a and t/v. Thus, we have in total four segments in Result 2.