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How to Launch a New Durable Good: A Signaling Rationale for Hunger Marketing☆

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ABSTRACT

We study the increasingly popular "hunger marketing" strategy (the combination of an artificially low price and a supply limit) adopted by many high-tech startups to launch their products. In a two-period model, a firm offers an artificially low introductory price and also imposes a limit on the quantity available for sale in the first period, which leads to a shortage in the equilibrium. We show that when effective word of mouth is present, such a strategy allows a firm to credibly convince the market of the premium quality of its product. We demonstrate that word of mouth plays a critical role in catalyzing the signaling mechanism. When word of mouth becomes more efficient, e.g., enabled by social media, shortage is larger in the equilibrium, and the introductory price falls further. Our study provides a rationale for hunger marketing.

1. Introduction

How can a new product quickly build a strong brand image? The phenomenal rise of Chinese smartphone manufacturer Xiaomi is an inspiring tale that deserves thoughtful examination. Xiaomi, which started receiving orders in 2011, has transformed itself from a startup to the third largest smartphone manufacturer in the world.[1] Many have praised Xiaomi's "hunger marketing" strategy and attributed the firm's success to it. Xiaomi sells its phones exclusively via online platforms in limited batches, which can sell out within seconds; this forces the many disappointed prospective customers to wait for the next flash sale. Xiaomi's hunger marketing practice differs substantially from that of premium brands, such as Apple and Sony, in selling their flagship products. Besides restricting its supply to create buzz in the market, Xiaomi couples tantalizing scarcity with the lure of bargains on price, which leads to a demand that far exceeds the supply. For instance, its flagship model M4 is similar in terms of configuration to Apple's iPhone 6, but sells for about half the price.[2]

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[1] http://www.wsj.com/articles/xiaomi-becomes-worlds-most-valuable-tech-startup-1419843430

[2] http://www.phonearena.com/phones/compare/Xiaomi-Mi-4,Apple-iPhone-6-Plus/phones/8777,8908

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0167-7187/

Many high-tech startups in the United States have adopted similar strategies that combine low prices with limited supply to launch their products. One notable success is the launch of Pebble Watch as “the first affordable smart watch.” In its unprecedentedly successful campaign on Kickstarter, a crowdfunding website, Pebble Technology offered the watch at a discounted price while limiting the number of pre-orders.

These observations puzzle market observers. Take Xiaomi, for example: Its rationed sales created arbitrage opportunities for online vendors, who were able to resell the phone for substantially more than its official price; the M4 was being traded for more than RMB 2,300 on major online consumer-to-consumer trading platforms, despite its official price tag of RMB 1,999.[3] Why does Xiaomi forgo the obvious excess demand, while paradoxically leaving money on the table?

Market observers have often attributed such supply limits to sellers' capacity constraints and viewed the buzz they create on social media as efforts to improve visibility. This paper, however, provides an economic rationale from a signaling perspective. Three features are common to the campaigns described above, which are similar to those of many other high-tech startups. First, in contrast to Apple, both Xiaomi and Pebble Technology were new entrants in the markets without established brand names or loyal clientele. Second, they sell high-tech durable goods that have relatively long life cycles, thereby precluding repeat purchases by experienced consumers within a short time window. As we will show later in the paper, conventional signaling devices could lose their bite in this context because of these two features. Third, social media has been used intensively by these firms to catalyze interactions between users and prospective consumers. Xiaomi, for instance, created an online community that allows users to exchange information and provide feedback. Pebble Technology promoted itself and its watch heavily and became one of the hottest topics on Kickstarter's discussion boards, as well as other popular social media platforms such as Facebook and Twitter. New companies are constrained in their ability to convince the market of their product's superior quality, given the lack of an existing reputation and the durable-good nature of its product. We demonstrate that the combination of low price and quantity limit, in the presence of the active and powerful word of mouth (WOM) enabled by social media, gives rise to an effective signaling mechanism.

A two-period model is created to depict the case described above. A durable good is launched in the market at the beginning of the first period, and consumers can purchase it in either period. Its quality can be either high or low and is privately known to the firm only. We find that when WOM is sufficiently powerful, a Pareto-dominant separating equilibrium exists. The high-quality firm sets an artificially low price in the first period, while imposing a limit on the quantity available for sales in the period. Consumers infer its premium quality, and the restricted supply thus leads to shortage in the presence of an overwhelming demand, thereby forcing unserved consumers to wait until the next period to pay a full-information price.[4]

The success of the signaling mechanism largely relies on effective WOM. In our context, this refers to *experiential word of mouth*—the most common form—which accounts for 50% to 80% of WOM activities.[5] The product is considered to be an experience good, so its quality is fully revealed upon consumption. Early buyers spread their feedback, e.g., by posting reviews online, thereby allowing a portion of unserved consumers to learn about the product. Speedy communication limits the profitability of a low-quality firm's mimicry, and facilitates credible signaling. To understand the logic, note that the high-quality firm in a separating equilibrium lowers its first-period price below the marginal production cost of its low-quality counterpart. Hence, sales in the first period incur a loss, even on a mimicking low-quality firm, and the firm must recoup its loss by profitable future sales. However, experiential WOM exposes the mimicking firm's inferior quality to the portion of unserved consumers who have received feedback, which squeezes its potential demand in the second period. WOM catalyzes a separating equilibrium and does not directly contribute to the high-quality firm's sales: Consumers purchase the high-quality firm's product not because of the recommendation via WOM; instead, they are convinced of its value upon observing the firm's credible signal, i.e., rationed sales at discounted price.

The high-quality firm's quantity choice in the first period involves subtle strategic trade-offs. On the one hand, the quantity available for sale must be limited to cause a significant shortage. The shortage caps its first-period loss and leaves sufficient remanent market for sales at the complete-information price in the second period. That is, offering only a small quantity for early sales signals the firm's confidence in future demand. On the other hand, the quantity cannot be excessively small. First, the loss, as a part of the signaling cost, must be sufficiently large to deter mimicry. Second, sufficiently broad experiential WOM must be in place to deter mimicry, which requires that nonnegligible early sales jump-start active interaction between early buyers and unserved consumers. The equilibrium choice must strike a balance between these concerns.

Our paper yields important insights about how WOM and social media contribute to marketing practices. WOM's power has long been recognized by both academia and practitioners. Consumers highly value opinions delivered to them directly,

[3] see http://android.tgbus.com/shouji/news/201408/502907.shtml (in Chinese).

[4] Take Xiaomi's pricing dynamics for example. A new edition of its M4 was selling for RMB 2,499. Xiaomi has continued to hike the price for its devices across the product line over the years (http://www.androidauthority.com/xiaomi-mi-6-great-deal-despite-25-percent-price-hike-766152/). As another example, Pebble Technology announced its Pebble Time in early 2015 and its fundraising plan. The watch initially sold for an introductory price of $149 in a limited batch, and the price was raised to $199 on formal release.

[5] A New Way to Measure Word-of-Mouth Marketing, *McKinsey Quarterly*, April 2010.

and WOM is estimated to have been the primary factor for up to 50% of all purchasing decisions.[6,7] The conventional view typically stresses the tailwind that positive feedback creates to promote sales.[8] Our study, however, stresses an alternative channel to harness its power: Negative WOM deters mimickry.

In the equilibrium, the more effective the WOM, the lower the introductory price and the more severe the shortage (i.e., the smaller quantity available) in the first period. This prediction provides a theoretical account for the anecdotes of many high-tech product launches, such as the aforementioned Xiaomi smartphones and Pebble Watch. The ascent of social media has transformed WOM from traditional one-to-one communication into a one-to-many broadcasting network, which tremendously expands the outreach of user feedback and accelerates its outspread. Our predictions could add to the playbook for marketing such products in the digital age.[9]

In addition, we demonstrate—by comparing the outcome of the separating equilibrium to that of a pooling equilibrium—that the aggressive signaling strategy can be excessively costly. Firms may prefer other marketing options when launching a product. Our results delineate the conditions under which such a signaling strategy is (not) preferable, which provides straightforward implications for marketing practice. The practical implications of our results will be further detailed at a later point.

The rest of the article proceeds as follows. We discuss our study's link to the relevant literature in the next section. The model is laid out in Section 3. Our analysis is described in Section 4; we begin with separating equilibria, then consider pooling equilibria. Section 5 concludes and summarizes the managerial implications of our findings.

2. Relevant Literature

How to effectively signal the quality of a product has been a canonical issue in economics and marketing literature.[10] It deserves to be noted that our paper depicts a context that differs from those in the standard literature, because it requires a two-dimensional signaling mechanism (low price coupled with shortage). We now briefly discuss the relavant literature.

Our context differs from those in which the usual Nelson effect looms large. Nelson (1974) suggests that dissipative expenditures, such as introductory prices or uninformative advertising, may signal quality. In a highly cited paper, Milgrom and Roberts (1986) formulate the Nelson argument and show that both introductory price and advertising (or other forms of dissipative marketing expenditures) can be used as quality signals. However, the Nelson effect in these studies relies on repeat purchases of nondurable goods, while in our context, the firm sells durable goods with a long life span, which nullifies dissipative expenditures as a *stand-alone* signaling device without first-period supply limit.

Our paper differs subtly, but distinctively, from Stock and Balachander (2005), who were among the first to expound on the signaling value of shortage ("scarcity," in their terminology).[11,12] In a model similar to Bagwell and Riordan (1991), a monopolist with private information about product quality sells to both informed and uninformed consumers, with informed consumers buying earlier than uninformed ones. The seller commits to the price and quantity of its product in the beginning of the model. Stock and Balachander show that the high-quality seller deliberately makes the product scarce for uninformed consumers, while avoiding price distortion by charging the complete-information price. This mechanism is tailored to a market environment in which a portion of consumers knows the quality of the product and purchases earlier. As price and quantity are pre-committed by the seller, uninformed consumers interpret shortage as a credible signal for high quality, because they infer that informed consumers have bought the product at the complete-information price.

Yu et al. (2016) also consider a two-period model—with an advance-selling period and a spot period—and allow for intertemporal pricing. In the early period, consumers are uncertain about both their own preference and the true quality of the product, while the uncertainty is resolved in the spot period when the product is released; e.g., the sales of concert

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6 Ibid.

7 A 2012 Nielsen study shows that 92% of consumers believe the recommendations of family and friends over all other forms of advertising; online consumer reviews are the second-most-trusted source of brand information. Global trust in advertising and brand messages (http://www.nielsen.com/us/en/insights/reports/2012/global-trust-in-advertising-and-brand-messages.html)

8 A classic case is Tupperware, which shunned formal ads for WOM campaigns in the form of "Tupperware parties." By recruiting women to host these informal parties for friends, family, and colleagues, Tupperware grew into a household name.

9 Xiaomi's limited sales, coupled with low prices, have been broadly interpreted as a deliberate choice of the firm and an example of the classic hunger marketing strategy (e.g., Dudovskiy (2018)). Competing rationales typically attribute the shortage to Xiaomi's lack of a robust supply chain, or its inability to estimate market demand. These arguments would have been more plausible when explaining Xiaomi's practice in its infant stage, when the start-up was constrained by limited experience and capacity in managing its supply-chain network, but less convincing when the firm had evolved into one of the leading smartphone manufacturers in the world. It would be difficult to dismiss poor supply chain management and capacity constraints as an explanation. However, the constraints, if present, would arguably have been the outcome of the firm's deliberate strategic choice, i.e., its insufficient resource allocation to its production, despite its rapid expansion in international markets.

10 The literature has proposed many devices that could effectively convey a product's quality information, including advertising (Kihlstrom and Riordan, 1984, Milgrom and Roberts, 1986), pricing (Bagwell and Riordan, 1991); warranties (Lutz, 1989); money-back guarantees (Moorthy and Srinivasan, 1995); umbrella branding (Wernerfelt, 1988); scarcity (Stock and Balachander, 2005); seller's waiting time (Gunay, 2014); and specializations (Kalra and Li, 2008).

11 The role of shortage or rationing has also been discussed in many other papers; however, they usually do not involve signaling (e.g., Becker (1991); DeGraba (1995); Denicolo and Garella (1999), etc.).

12 Bandyopadhyay, Dong, and Qin (2018) also study a signaling game in which the seller induces a shortage by properly setting its price in the first stage. In a model similar to that of Milgrom and Roberts (1986), they consider nondurable goods and allows for repeat purchase and show that a seller-induced shortage could outperform signaling with the introductory price and dissipative advertising.

tickets. A high-quality firm sells a strictly smaller quantity than its low-quality counterpart for advance sales in the first period.

We will elaborate more on how our paper differs from the above-mentioned studies Section 4.1.2 after presenting the technical details and main result. In addition, similar to our study, Kennedy (1994) demonstrates the role played by WOM in deterring mimicry. However, Kennedy considers overlapping generations, which resembles a model with repeat sales, thereby dismissing supply limit in signaling. Ellison and Fudenberg (1995) investigate the fundamental mechanism through which word of mouth aggregates individual agents' information and coordinates their actions. Marketing researchers have long recognized the power of WOM as a driver for sales. More than half a century ago,) Katz and Lazarsfeld (1995) demonstrated that it is the single most importance source of information for certain household items. More recently, the rise of social media has attracted tremendous research effort, and many empirical studies have documented the effectiveness of online WOM marketing for various products, such as books and movies (e.g., Chevalier and Mayzlin (2006); Liu and Young (2006); Trusov et al. (2009)).

3. The Model

We consider a dynamic durable-good model with incomplete information. A firm plans to launch an innovative product whose life cycle lasts two periods. The quality of the product can be either high (h) or low (l). The former possibility occurs with a probability $\theta \in (0, 1)$, while the latter is realized with the complementary probability $1-\theta$. The probabilistic distribution of product quality is common knowledge, while its exact realization is privately known only by the firm, which defines its type (t). For simplicity, we assume that the product is manufactured at a constant marginal cost c_t, with $c_h \geq c_l > 0$.

Each consumer purchases at most one unit of the product. The total size of the market is normalized to unity without loss of generality. Consumers have homogeneous valuation for the product, and one obtains a utility $v > c_h$ if a high-quality product is bought and 0 otherwise. A consumer's utility function is thus given by:

$$u = \begin{cases} v-p & \text{if a high-quality product is purchased at price } p, \\ -p & \text{if a low-quality product is purchased at price } p. \end{cases} \tag{1}$$

It should be noted that our qualitative predictions do not rely on the assumption of homogeneous consumers.[13]

In the beginning of the first period, the type-t firm simultaneously announces its price $p_1^t \in [0, v]$ and the quantity s^t available for sale for the period. Following the convention in the literature on durable goods (e.g., Coase, 1972), we assume that the firm is unable to precommit to the price it will charge in the second period.[14] Consumers form their posterior beliefs about product quality upon observing the bundle (p_1, s), denoted by $b_1(p_1, s)$, as well as the conjecture about the equilibrium price p_2 that will be charged by the firm in the second period, and decide whether to purchase the product immediately. Formally, let $a_1(p_1, s) \in \{0, 1\}$ be a consumer's decision upon observing the price-quantity pair (p_1, s), with $a_1(p_1, s) = 0$ if one chooses not to purchase the product immediately and $a_1(p_1, s) = 1$ if he does. We focus on the case in which all of the consumers adopt the same strategy. As a result, the quantity demanded by consumers in this period, denoted by $\hat{s}(p_1, s)$, is the same as $a_1(p_1, s)$.

If $\hat{s} > s$, a shortage results and the product must be rationed among consumers who are willing to pay the price p_1. We define $\tilde{s} = \min(\hat{s}, s)$, which denotes the actual number of consumers who purchase and experience the product in the first period. If all consumers are served in the first period, i.e., $\hat{s}(p_1, s) = s = 1$, the game ends. Otherwise, it proceeds into the second period, and WOM occurs instantaneously—i.e., served consumers send messages about their consumption experience. We assume that the product is an experience good, so the quality of the product is fully revealed to users upon consumption. Early users' messages are amplified through experiential WOM, allowing the true quality of the product to be learned by a total of $\phi(\tilde{s})$ consumers—including message senders themselves—with $\phi(\tilde{s}) > \tilde{s}$. Among them, $\phi(\tilde{s}) - \tilde{s}$ are still unserved, while the rest of the market—i.e., the $1-\phi(\tilde{s})$ consumers who have neither experienced the product nor been reached by WOM—remains uninformed, and maintains the posterior formed based on Bayesian updating after observing the firm's behavior.

We impose fairly mild regularity conditions for the technology of WOM communication $\phi(\tilde{s})$. First, WOM stems out of early users' experience and is spread to unserved consumers, which requires, by definition, $\phi(0) = 0$, $\phi(1) = 1$ and $\phi(\tilde{s}) > \tilde{s}$ for $\tilde{s} \in (0, 1)$. Second, the spread of WOM communication presumably increases with the number of served consumers $\tilde{s}$, with $\phi' > 0$. Third, we assume that the function is smooth and concave, with $\phi'' < 0$.[15] Consider an alternative technology $\eta(\tilde{s})$. If $\phi(\tilde{s}) > \eta(\tilde{s})$ for all $\tilde{s} \in (0, 1)$, ϕ indicates a speedier WOM communication than η. Our main results are derived under the specifications of a general functional form $\phi(\tilde{s})$, but we adopt a more stylized setting for WOM for handy comparative static analysis, which illustrates the underlying logic of the model.

In the second period, depending on (p_1, s) and $\tilde{s}$, the type-t firm sets its price $p_2^t(p_1, s; \tilde{s}) \in [0, v]$ and announces it publicly. The uninformed consumers—i.e., those who have neither purchased the product nor been reached by WOM—can further update their beliefs to $b_2(p_2|(p_1, s))$ upon observing p_2 and decide whether to purchase the product. Let

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13 A brief analysis is provided in Online Appendix.

14 As will be discussed later in the paper, our results remain largely intact even if the second-period price is allowed to be precommitted.

15 Concavity, coupled with the fact of $\phi(0) = 0$, $\phi(1) = 1$, implies $\phi'(0) > 1$ and $\phi'(1) < 1$.

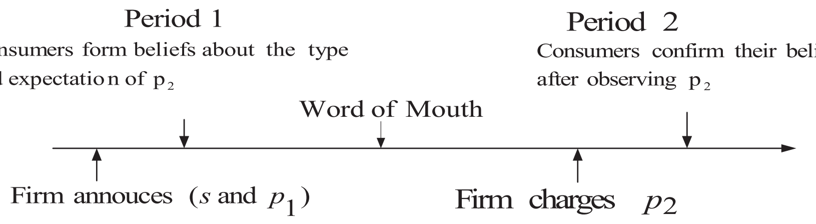

Fig. 1. Timeline of the model

$a_2(p_2|(p_1,s)) = 1$ if they purchase and 0 if not. Denote by $\hat{s}_2(p_2|(p_1,s))$ the quantity demanded by the set of unserved consumers upon observing the price. It can be seen that $\hat{s}_2 = a_2(1-\phi(\tilde{s})) + (\phi(\tilde{s})-\tilde{s})I_{\{t=h\}}$.

For the sake of simplicity, we assume that quantity setting is not a part of the firm's strategic actions in the second period. The firm is willing to meet consumers' demand in this period for price $p_2 \geq c_t$. It thus earns a profit in the period $(p_2-c_t)\hat{s}_2(p_2|(p_1,s))$. We further assume that neither the firm nor the consumers discount their future payoffs.

The sequence of events is illustrated in Figure 1.

For the incomplete-information sequential game, we adopt *Perfect Bayesian equilibrium* (PBE) as the solution concept. A PBE consists of the type-t firm's behavioral strategy $\left\{(p_1^t, s^t);\, p_2^t(p_1,s,\tilde{s})\right\}$, the consumers' strategy $\{a_1(p_1, s), a_2(p_2|(p_1, s))\}$ and beliefs $b_1(p_1, s)$ and $b_2(p_2|(p_1, s))$, such that the following requirements are met.

1. Given $\left\{p_1^t, s^t, p_2^t(p_1,s,\tilde{s})\right\}$ and their beliefs, $a_1(p_1,s) = 1$ if and only if $b_1(p_1,s)v - p_1 \geq \max\{0, E[b_2v - p_2|(p_1,s)]\}$, and $a_2(p_2|(p_1,s)) = 1$ if and only if $b_2(p_2|(p_1,s))v - p_2 > 0$.
2. Beliefs are formed via Bayesian rule whenever possible.
3. Given $a_1(p_1, s)$ and $a_2(p_2|(p_1, s))$, $\left\{p_1^t, s_1^t, p_2^t(p_1,s_1,\tilde{s})\right\}$ maximizes the type-t firm's overall profits:
$$\left(p_1^t - c_t\right)\tilde{s}_1\left(p_1^t, s^t\right) + \left(p_2^t - c_t\right)\hat{s}_2\left(p_2^t\left|\left(p_1^t, s^t\right)\right.\right).$$
4. Given the history $(p_1, s_1, \tilde{s})$ and consumers' action $a_2(p_2|(p_1, s))$, p_2^t maximizes the type-t firm's profit in the second period: $(p_2^t - c_t)\hat{s}_2(p_2^t|(p_1^t, s^t))$.

The equilibrium requires that consumers' purchase decisions be supported by rational beliefs formed based on Bayesian rule. Condition (3) requires that the behavioral strategy $\left\{(p_1^t, s^t);\, p_2^t(p_1,s,\tilde{s})\right\}$ maximize the firm's profit. Condition (4) resembles the requirement of *sequential rationality* for sequential equilibrium (Kreps and R., 1982), demanding that the firm maximize its profit at every possible information set along a dynamic path. Again, we must highlight that the firm does not precommit to a price p_2 in the beginning of the game. However, the firm, given a history $(p_1, s, \tilde{s})$, has no incentive to deviate from an equilibrium $p_2(p_1, s, \tilde{s})$, which is rationally conjectured by consumers.

We focus on pure-strategy equilibria and consider both separating and pooling equilibria. Because PBE imposes few restrictions on out-of-equilibrium belief, multiple equilibria emerge in the game as usual. As will be discussed later in the paper, common refinement techniques, such as generalized intuitive criterion (Cho, 1987) and divine criterion (Banks and Sobel, 1987), do not apply, in general, in our context. In our discussion, we follow Bagwell and Riordan (1991) and focus more on Pareto-dominant equilibria from the firm's perspective.

Three remarks are in order. First, we require that the firm's prices (p_1, p_2) be capped by consumers' reservation values v. Relaxing the restriction does not affect our main results. It does, however, help rule out trivial equilibria, thereby allowing us to focus on the most sensible predictions and simplify our presentation.

Second, two features distinguish our model from previous frameworks. Unlike Stock and Balachander (2005) and Bagwell and Riordan (1991), informed consumers are not present in our setting. Our model is tailored to model marketing strategies for launching new-to-the-world products developed by firms without an established reputation or clientele. Unlike Milgrom and Roberts (1986), a consumer in our model exits the market once he purchases one unit of the product in the first period and does not return for repurchase. Our model is set up to depict the strategy to sell durable goods with relatively long life cycles. However, our model also accomodates enviroments that involve repeat purchase and informed consumers.[16]

Finally, it's straightford to see that in its complete-information version of the model the high-qualility firm charges a price v and sells to all consumers in the first period. Thus, neither introductory price nor stockout occurs in the equilibrium.

4. Equilibrium Analysis

Next, we conduct formal analysis to characterize the equilibria of this signaling game and describe their main properties. We first consider separating equilibria in which the firm employs type-dependent strategies, then proceed to pooling equilibria in which the firm's strategy does not convey any additional information. We focus on these two extreme types of equilibria, as hybrid equilibria are simply the mixture of the two.

[16] Extensions to repeat purchase and informed consumers are available upon request from the authors.

4.1. Separating Equilibria

In the beginning of the first period, the firm announces its price-quantity pair (p_1^t, s^t), where the superscript t denotes the firm's type. Consumers form their posterior $\Pr(t = h|p_1, s_1)$ about the firm's type and a conjecture of the price p_2 it will charge in the future. The dynamic nature of our model gives rise to additional complications in the belief-formation process: Consumers could presumably obtain additional information upon observing p_2, which could allow them to revise the posterior formed previously based on (p_1^t, s^t).

A separating equilibrium requires that consumers make perfect inferences about the firm's type after observing $\left\{(p_1^t, s^t);\, p_2^t(p_1, s, \tilde{s})\right\}$, i.e., $\left\{(p_1^t, s^t);\, p_2^t(p_1, s, \tilde{s})\right\} \neq \left\{(p_1^{t'}, s^{t'});\, p_2^{t'}(p_1, s, \tilde{s})\right\}, t, t' \in \{h, l\}$. We hereby search for separating equilibria with $(p_1^h, s^h) \neq (p_1^l, s^l)$, which allows consumers to perfectly distinguish between the two types upon observing (p_1, s). There could exist a continuum of trivial separating equilibria with $(p_1^h, s^h) = (p_1^l, s^l)$ and $p_2^h \neq p_2^l$ under the condition of $\theta v \geq c_h$: In such equilibria, the firm charges $p_1^h = p_1^l = p \in [c_h, \theta v]$ and sets $s^h = s^l = 1$ regardless of its type, and charges p_2 differently with $v - p_2^h \leq \theta v - p_1$. Such equilibria lead to $\tilde{s} = 1$ —i.e., all consumers are served in the first period—and are in essence no different from pooling equilibria in terms of equilibrium outcomes. This is because information updating—based on p_2—does not affect strategic plays in the second period, given that consumers no longer make purchase decisions.

Let us term an equilibrium with $(p_1^h, s^h) \neq (p_1^l, s^l)$ a *sensible separating equilibrium*. In such an equilibrium, $\Pr(t = h|p_1^h, s^h) = 1$ and $\Pr(t = h|p_1^l, s^l) = 0$. As a result, the low-quality firm must end up with zero profit. As stated above, such an equilibrium requires that a type-t firm have no incentive to deviate from the second-period price p_2^t rationally conjectured by consumers.

For the high-quality firm, setting a price-quantity pair (p_1^h, s^h) leads to a first-period profit

$$\left(p_1^h - c_h\right)\tilde{s}^h$$

where $\tilde{s}^h = \min(\hat{s}^h, s^h)$ is the actual quantity sold given the committed quantity offered and the quantity consumers demand upon observing (p_1^t, s^t) in the first period. In the hypothetical sensible separating equilibrium, the high-quality firm receives an overall profit

$$\pi_h = \left(p_1^h - c_h\right)\tilde{s}^h + \left(p_2^h - c_h\right)\hat{s}_2\left(p_2^h\middle|(p_1^h, s^h)\right). \tag{2}$$

The payoff π_h must be nonnegative to ensure that the high-quality firm's IR condition holds.

A consumer, upon observing (p_1^h, s^h), must decide whether to buy now at price p_1^h or wait until the next period to buy at price p_2^t. Because the firm's price is assumed not to exceed v, a consumer would make an immediate purchase if and only if $p_1^h \leq p_2^h$ in a separating equilibrium. It should be noted that in a sensible separating equilibrium, the high-quality firm does not necessarily set a price $p_2^h = v$: The forward-induction approach of PBE does not restrict consumers' conjecture of p_2, and the solution concept imposes little restriction on consumers' belief when they observe a price that deviates from their conjecture. The following lemma characterizes the set of admissible second-period prices and actual quantities of first-period sales in any sensible separating equilibrium.

Lemma 1. *In any sensible separating equilibrium, the high-quality firm sells a positive quantity $\tilde{s}^h = s^h \in (0, 1)$ but does not fully cover the market in the first period; in the second period, it sets a price $p_2^h \in (c_h, v]$ and sells to the whole set of unserved consumers, i.e., $\hat{s}_2\left(p_2^h\middle|(p_1^h, s^h)\right) = 1 - s^h$; the high-quality firm's price must increase over the two periods, i.e., $p_1^h \leq p_2^h$.*

Proof. All proofs can be found in the Appendix. □

The lemma states that a sensible separating equilibrium requires that positive sales occur in the first period, but the market not be fully served. In the second period, the high-quality firm earns strictly positive profit from each unit of sales and sells to all unserved consumers. Hence, the high-quality firm's total profit in the hypothetical equilibrium would amount to

$$\pi_h = \left(p_1^h - c_h\right)s^h + \left(p_2^h - c_h\right)(1 - s^h) \geq 0. \tag{3}$$

The lemma further requires that the high-quality firm's price increase over the periods, with

$$p_1^h \leq p_2^h, \tag{4}$$

which is consumers' incentive compatibility condition (IC). This ensures that consumers are willing to pay p_1^h in the first period instead of waiting until the next period, which helps sustain a separating equilibrium.

We now characterize the incentive compatibility conditions (IC) for such an equilibrium. Suppose that the low-quality firm mimics its high-quality counterpart by replicating its strategy in the first period. It receives a first-period profit $\left(p_1^h - c_l\right)s^h$. Next, consider the behavior of the mimicking low-quality firm in the second period. Word of mouth plays a crucial role, making a separating equilibrium likely: In contrast to the case of the high-quality firm, a total of $\phi(s^h)$ consumers are disillusioned and correct their beliefs accordingly. The rest of the market—with the size of $1 - \phi\left(s^h\right)$—maintains the posterior formed previously. As a result, the low-quality firm has a potential demand of $1 - \phi\left(s^h\right)$, which is strictly less than that of its high-quality counterpart, $1 - s^h$. The more effective the communication, i.e., smaller α, the larger this differential.

For simplicity, we assume that in the second period, consumers who have observed $((p_1^h, s^h), p_2)$ with $p_2 \neq p_2^h(p_1^h, s^h, \tilde{s}^h)$ believe it is the low-quality firm that has deviated. Hence, the low type, if having mimicked by setting (p_1^h, s^h), would have no incentive to set a price $p_2 \neq p_2^h(p_1^h, s^h, \tilde{s}^h)$ in the second period.

As a result, to ensure that the low-quality firm does not imitate its high-quality counterpart in a separating equilibrium, the following IC must be satisfied:

$$\left(p_1^h - c_l\right)s^h + (p_2^h - c_l)\left[1 - \phi\left(s^h\right)\right] \leq 0. \tag{5}$$

Any separating equilibrium must satisfy conditions (5) and (3).

As for the high-quality firm, in any sensible separating equilibrium we must have

$$(v - c_h)\left[\phi\left(s^h\right) - s^h\right] \leq \left(p_2^h - c_h\right)\left(1 - s^h\right). \tag{6}$$

Condition (6) is the IC condition for the high-quality firm, which ensures that it has no incentive to deviate from the price p_2^h as rationally expected by consumers. By assuming that consumers believe that a price that deviates from p_2^h is set by the low-quality firm, the high-quality firm's most profitable deviation requires setting a price $p_2 = v$, in which case it sells only to those who are unserved but have learned the true quality of the product via WOM.

4.1.1. Equilibrium Characterization and Main Properties

The preliminaries laid out above allow us to obtain the following.

Proposition 1. *(a) A sensible separating equilibrium requires that conditions (3), (4), (5), and (6) be satisfied; conversely, any triplet* $((p_1^{h*}, s^{h*}); p_2^{h*})$ *that satisfies conditions (3), (4), (5), and (6) can constitute a sensible separating equilibrium, supported by a belief that any action that deviates from* $((p_1^{h*}, s^{h*}); p_2^{h*})$ *is made by the low-quality firm.*

(b) In a sensible separating equilibrium, the high-quality firm's prices rise over time, i.e., $p_1^{h*} < c_l \leq c_h < p_2^{h*}$*; all consumers demand the product in the first period at price* p_1^{h*}*, and the high-quality firm sells to only a portion of them, i.e.,* $s^{h*} < \hat{s}(p_1^{h*}, s^{h*}) = 1$.

Proof. All proofs can be found in the Appendix. □

Proposition 1 describes the main properties of the signaling mechanism. In a complete-information benchmark, the high-quality firm would sell to all consumers in the market at their reservation utility v in the first period. In contrast, the high-quality firm charges a price $p_1^{h*} < c_l$ in a separating equilibrium; consumers make perfect inferences upon observing (p_1^{h*}, s^{h*}), but a shortage is incurred in the equilibrium because $s^{h*} < 1$. The combination of a low introductory price and an equilibrium shortage (quantity limit) allows the high-quality firm to distinguish itself from its low-quality counterpart, both effectively and profitably. The high-quality firm bears a loss in the first period and makes up for the loss in the second period. Word of mouth plays a subtle but critical role: With a quantity $s \in (0, 1)$ sold in the first period, WOM allows additional $\phi(s) - s$ consumers to learn the true quality in the second period and be immune to any deception, thereby limiting the low-quality firm's profitability from mimicry. The quantity choice in the first period thus involves subtle strategic trade-offs. It must be sufficiently large in order to spark experiential WOM that prevents mimicry; it must also be limited, however, as excessive loss would otherwise be incurred, and future profitable sales would be cannibalized: Note that the high-quality firm sells to $1 - s^{h*}$ consumers in the second period.

There are numerous possible combinations of p_1^{h*}, s^{h*}, and p_2^{h*} that could satisfy the conditions, and the equilibria are definitely not unique. Following Bagwell and Riordan (1991), we subsequently focus on sensible separating equilibria that are Pareto-dominant from the firm's perspective.[17] Because the equilibria require zero profit for the low-quality firm, we simply search for eligible $((p_1^{h*}, s^{h*}); p_2^{h*})$ that allow the high-quality firm to secure the maximally possible equilibrium payoff.

To identify the Pareto-dominant equilibrium, we solve

$$\max_{(p_1, s); p_2} (p_1 - c_h)s + (p_2 - c_h)(1 - s)$$

$$s.t.\ (p_1 - c_l)s + (p_2 - c_l)(1 - \phi(s)) \leq 0.$$

Simple math allows us to obtain the following.

Proposition 2.

(a) *Let* $s^{h*} = \arg\max\{\phi(s) - s\}$*. As long as* $\phi\left(s^{h*}\right) - s^{h*} > \frac{c_h - c_l}{v - c_l}$*, i.e. when word-of-mouth communication is sufficiently effective, there exists a Pareto-dominant sensible separating equilibrium.*

(b) *The high-quality firm sets a introductory price* $p_1^{h*} = c_l - (v - c_l)\left(\frac{1 - \phi(s^{h*})}{s^{h*}}\right) < c_l$ *and serves a fraction of demand in the first period, with* $s^{h*} = \arg\max\{\phi(s) - s\} < 1$*; it charges full-information price* $p_2^{h*} = v$ *in the second period and sells to the entire remanent market* $1 - s^{h*}$.

[17] Equilibrium refinement will be discussed later in the paper.

Proof. All proofs can be found in the Appendix. □

We conduct comparative statics on the equilibrium, which further unveils the logic of the equilibrium and, in particular, the role played by WOM. Recall that the high-quality firm has to price its product sufficiently low in the first period in the equilibrium. We define $\psi = (v - p_1^{h*})s^{h*}$ as a measure of the cost of effective signaling, which is the revenue sacrificed compared with a complete-information benchmark.

Proposition 3. *Suppose $\phi(s) > \eta(s)$for all $s \in (0, 1)$. When the diffusion rule changes from $\eta(s)$ to $\phi(s)$, i.e., the word-of-mouth communication becomes more efficient, the high-quality firm bears a lesser signaling cost.*

Proof. All proofs can be found in the Appendix. □

However, more efficient WOM always benefits the high-quality firm, as it implies a more effective signaling mechanism. This is evidenced by the claim of Proposition 3: The signaling cost decreases when more powerful WOM is available.

Next, we consider a stylized setting for WOM to enable handy comparative statics, which further illuminates the underlying nuances of the signaling mechanism. In particular, let $\phi(\tilde{s}) = \tilde{s}^{\alpha}$. Obviously, it satisifies the regularity conditions imposed for $\phi(\tilde{s})$ in Section 3, with $(\tilde{s}^{\alpha})' > 0$ and $(\tilde{s}^{\alpha})'' < 0$. Note that $\tilde{s}^{\alpha}$ decreases with the parameter α, which measures the effectiveness of the WOM. A smaller α indicates a speedier outspread of the message, while the communication is entirely muted if $\alpha = 1$. The following is obtained.

Proposition 4. *Suppose $\phi(\tilde{s}) = \tilde{s}^{\alpha}$, when WOM becomes more efficient, i.e., α decreases, in the Pareto-dominant sensible separating equilibrium,*

(a) *the high-quality firm's first-period price is lower, and the resultant shortage is more pronounced, i.e., $\frac{dp_1^{h*}}{d\alpha} > 0$ and $\frac{ds^{h*}}{d\alpha} > 0$;*
(b) *the share of endogenously created informed consumers $(s^{h*})^{\alpha}$—who either have experienced the product or learned about its quality through WOM—strictly increases, i.e., $\frac{d(s^{h*})^{\alpha}}{d\alpha} < 0$.*

Proof. All proofs can be found in the Appendix. □

Thus, s^{h*} strictly increases with α. That is, the more efficient the WOM (a smaller α), the more pronounced the shortage (smaller s^{h*}) in the first period. The intuition is straightforward. Recall that WOM deters the low-quality firm's mimicry: The larger $(s^{h*})^{\alpha}$, the more costly the low-quality firm's mimicry. However, early sales are costly, because they not only incur loss in the first period, but also reduce sales in the future. More powerful WOM allows the high-quality firm to avoid the loss by further cutting back s^{h*}. This is because a relatively deep cut in s^{h*} would not substantially reduce the outreach $(s^{h*})^{\alpha}$, as it is partially offset by the decrease in α. This leads the high-quality firm to further limit its early sales and preserve a larger remanent demand $1 - s^{h*}$, as shown by Proposition 4(a). At the same time, the decrease in s^{h*} implies a smaller cost for mimicry, which, in turn, compels the high-quality firm to further cut p_1^{h*} to deepen the loss to its low-quality counterpart when it mimics.

Note that when α continues to drop—i.e., when WOM is increasingly powerful—p_1^{h*} could drop below zero. In that case, the high-quality firm could even give away free samples or even pay consumers to experience its product.

4.1.2. Comparison to Other Studies

We now elaborate more on how our model and results are connected to the literature. First, our study stands in contrast to that of Bagwell and Riordan (1991). They find that the price of a high-quality good is upward distorted initially. A key assumption by Bagwell and Riordan is that some consumers are exogenously informed about product quality before purchase. Consequently, a high-quality firm signals its type by upward price distortion: The firm does not mind the lack of demand at an artificially high price, because it is confident of its sales to informed consumers, who can recognize premium quality and are willing to pay for it. In our context, in contrast, all consumers are initially uninformed about product quality. To screen out its low-quality counterpart, a high-quality firm must resort to an artificially low introductory price to allure uninformed consumers to experience the good.

Our signaling mechanism is thus more in line with that of Milgrom and Roberts (1986), who find that the high-quality firm can use an artificially low introductory price or engage in other form of dissipative marketing expenditures (such as uninformative advertising) to communicate with uninformed consumers. However, their model relies heavily on consumers' repeated purchase. In contrast, in our context, the firm sells durable goods with a long life span, which nullifies dissipative expenditures as a *stand-alone* signaling device without first-period supply limit: The latter limits loss and preserves future sales despite the artificially low introductory price in the first period, while the former rewards the high-quality firm by sparking WOM to prevent mimicry.[18] As a result, both quantity limit and effective WOM are indispensable:

Our model differs from that of Stock and Balachander (2005) in three respects. First, in their model, quantity is a stand-alone signaling device that substitutes for the use of price distortion to convey information. In contrast, our model requires a combination of low price and quantity limit, with the two instruments *complementary* to each other. Second, Stock and

[18] Linnemer and Laurent (2012) describes a context in which a monopolistic seller's quality and cost are both uncertain and continuous. The paper shows that separating equilibria exist in which the firm signals by a mix of price and dissipative advertising.

Balachander assume that prices are constant for early and late buyers, while we allow prices charged by the firm to vary intertemporally. Third, Stock and Balachander focus on a market environment in which informed consumers exist—for instance, when an established firm launches a new version of a product in an existing product line, e.g., when Sony introduced its PlayStation 2 in 2011. In contrast, we consider the launch of a new-to-the-world durable good, in which neither expert consumers nor repeat purchase are available. This requires a lower introductory price to jumpstart sales, while simultaneously limiting early supply to minimize early loss and keeping future demand. Our study thus complements that of Stock and Balachander in this regard.

Our model differs from that of Yu et al. in several aspects. First, they assume that the product is released only in the spot period, and uncertainty is resolved instantaneously; consumers who purchase it in advance do not have immediate consumption. In contrast, we assume that the product is ready for consumption from the beginning of the game, and a consumer's uncertainty cannot be resolved unless she consumes it or receives WOM feedback. Second, early sales in our model incur a substantial loss in the separating equilibrium, because of excessive downward price distortion, but spark WOM; this enables the signaling mechanism in our model. In contrast, advance sales in Yu et al. are profitable and could increase the firm'sales by taking advantage of the uncertainty in consumers' preferences. The two studies thus complement each other.

Furthermore, it merits noting, again, that the strategic rationale of quantity limit in our model differs subtly and fundamentally from that in Stock and Balachander (2005) and Yu et al. (2016), as they entail different strategic calculations. In those studies, the high-quality firm strategically cut supply from the optimal level to signal the hidden quality, which hurts its sales. In our study, the quantity limit in the first period serves to preserve future demand and allows the high-quality firm to serve the whole market at the complete-information price in the second period. The high-quality firm must supply a sufficiently large quantity for early sales at a discounted price to amplify the outreach of the resultant WOM, which enables the novel signaling mechanism highlighted in our model.

4.1.3. Equilibrium Refinement

Signaling games typically generate multiple equilibria, as does our model. However, the usual refinement techniques, such as generalized intuitive criterion (Cho, 1987) and divinity criterion (Banks and Sobel, 1987), would lose their bite, as in Bagwell and Riordan.

In contrast to standard Spence-type signaling games, in which the sender (employee) pays for its signal (education) directly (Spencer, 1973), signaling itself does not involve direct payment from the sender (the firm) in our model. Instead, the cost of signaling stems from the firm's sales at an artificially low price. As a result, almost all deviation in (p_1, s) —as well as in the expected price p_2 on an equilibrium path— that benefits the high-quality firm under certain consumer beliefs also renders its low-quality counterpart better off. Consequently, consumers, in general, cannot associate a deviation with the high-quality firm, as in standard Spence-type games.

The difficulty, which is typical to pricing games with signaling elements, is further compounded by the dynamic structure of the game. The firm announces its price p_2 in the second period, which presumably can convey new information and allow consumers to revise the belief formed after observing (p_1, s). The cross-period reflexive interaction gives rise to numerous possible equilibrium paths that can be supported by arbitrary belief systems, but are self-fulfilling. Our setup does not prohibit consumers from updating their beliefs again when observing p_2 in the second period, which partly contributes to the multiplicity of equilibria. If we adopt the notion of passive belief (Cramton, 1985; Rubinstein, 1985) —which assumes away the dynamic belief-updating process, letting consumers' posterior degenerate to that formed in the first period—many equilibria can be ruled out, and the prediction coincides with that under our current Pareto-dominance approach.

4.2. Pooling Equilibria

The game generates multiple equilibria, as in typical signaling models. We now discuss the existence and characteristics of pooling equilibria, in which the firm plays a type-independent strategy and consumers must maintain their prior throughout. Due to the dynamic nature of our model, four types of pooling equilibria could exist, which are summarized below based on their equilibrium outcomes.

1. (**Type-I pooling equilibria**): zero transactions in the first period, but positive sales in the second for both types of firms.
2. (**Type-II pooling equilibria**): positive sales for both types of firms in both periods.
3. (**Type-III pooling equilibria**): positive sales for the high-quality firm in both periods, and positive sales for the low-quality firm in the first period only.
4. (**Type-IV pooling equilibria**): positive sales that fully cover the market in the first period, i.e., $\tilde{s} = 1$.

Types I, II, and IV pooling equilibria are relatively trivial, as they involve little strategic essence. These equilibria would not exist when we focus on the case of a sufficiently pessimistic prior, i.e., a sufficiently small θ. The conditions for the existence of these equilibria are summarized in Table 1, and the proof is available from the authors upon request. Type-III pooling equilibria involve more sophisticated strategic trade-offs, and a comparison between such equilibria and separating equilibria yields interesting implications. We hereby focus on this type of equilibria. It should be noted that Type-III equilibria degenerate to Type-IV equilibria when the quantity set for early sales exceeds one under certain conditions.

Table 1
Types of Pooling Equilibria

	$0 \le \theta \le \frac{c_l}{v}$	$\frac{c_l}{v} \le \theta \le \frac{c_h}{v}$	$\frac{c_h}{v} \le \theta \le \frac{(1-\phi'(1))v+\phi'(1)c_h}{v}$	$\frac{(1-\phi'(1))v+\phi'(1)c_h}{v} \le \theta \le 1$
Pooling Equilibrium	None	Type III	Type I,II,III and IV	Type I,II and IV

In such an equilibrium, the firm sets type-independent price-quantity pair (p_1, s) in the first period. It makes positive sales in the first period, but does not fully cover the market; in the second period, only the high-quality firm makes sales. That is, the firms of both types set a first-period price no more than the reservation value under prior, θv, which leads consumers to buy under their prior; in the second period, only those who have fully learned about the true quality of the product through WOM make purchase at the full-information price v from the high-quality firm, although the price is charged by both types of firms in a pooling equilibrium. The $1 - \phi(\tilde{s})$ consumers who are not reached by WOM are unwilling to pay v given that their belief remains to be the prior.

Such equilibria can thus be characterized by the following necessary and sufficient conditions, with the off-equilibrium-belief that any deviation is associated with a low quality:

$$(p_1 - c_l)\tilde{s} \ge 0;$$
$$(p_1 - c_h)\tilde{s} + (v - c_h)(\phi(\tilde{s}) - \tilde{s}) > 0;$$
$$p_1 \le \theta v.$$

The first two inequalities are the participation constraints for the low- and high-quality firms, respectively. The third is consumers' participation constraint in the first period. As will be shown later, the existence of such equilibria requires that the prior not be excessively pessimistic, i.e., $\theta \ge \frac{c_l}{v}$, which makes it possible that the low-quality firm will mimic its high-quality counterpart by charging a price θv profitably.

Similar to the case of separating equilibria, standard refinement techniques, e.g., the generalized intuitive criterion proposed by Cho (1987), do not apply in general. Again, we follow Bagwell and Riordan (1991) to search for Pareto-dominant equilibria for the firm.

Proposition 5.

(a) *When $\theta \in [\frac{c_l}{v}, \frac{(1-\phi'(1))v+\phi'(1)c_h}{v}]$, i.e., the prior about product quality is not excessively optimistic, there exists a unique Pareto-dominant Type-III pooling equilibrium.*

(b) *In the equilibrium, the firm sets a type-independent price-quantity pair (p_1^*, s^*) in the first period, with $p_1^* = \theta v$ and $s^* < 1$ where $\phi'(s^*) = \frac{(1-\theta)v}{v-c_h}$, and all consumers are willing to buy the product at price p_1^*; in the second period, the firm sets a price $p_2^* = v$, and only the high-quality firm is able to sell to the $\phi(s^*) - s^*$ unserved consumers who have been reached by WOM.*

(c) *In the equilibrium, both types of firms end up with positive profits. The high-quality firm earns a profit*

$$\pi_h^* = (\theta v - c_h)s^* + (v - c_h)(\phi(s^*) - s^*),$$

and the low-quality firm earns $\pi_l^* = (\theta v - c_l)\ s^*$.

Proof. All proofs can be found in the Appendix. □

Comparison of the types of equilibria (Type-III pooling equilibrium and sensible separating equilibrium) further illuminates the nature of the signaling mechanism. They have three features in common. First, shortage also emerges in the pooling equilibrium: In the first period, all consumers are willing to pay θv for the product, but the firm does not satisfy the entire demand ($s^* < 1$). Second, the high-quality firm may still bear a loss in the first period, although it hurts the firm less than in the separating equilibrium: When the prior is sufficiently pessimistic, i.e., $\theta < \frac{c_h}{v}$, the price θv does not offset its production cost. Third, the price rises in the second period to the full-information price $p_2^* = v$.

However, the combination of shortage (quantity limit) and first-period loss for the high-quality firm plays a sharply different role than in the separating equilibrium. It does not communicate the hidden quality information to the whole market as a signaling device, and consumers—except for early users and recipients of WOM feedback—maintain their prior throughout. This leads to two outcomes that diffentiate the pooling equilibrium from its separating countepart. First, in the former, the high-quality firm charges a low price to create initial demand and subsequently sells at the full-information price to the $\phi(s^*) - s^*$ consumers only, taking advantage of the spread of positive feedback to allure future purchases, while the low-quality firm sells nothing. In contrast, in the latter, the high-quality firm sells to all $1 - s^*$ unserved consumers in the second period, regardless of their access to WOM feedback, in which case WOM serves only to deter mimicry. Second, in the former, one observes with a positive probability that a firm's sales fall short of demand in the first period but do not last to the second, which occurs when the firm is of low quality; in contrast, in the latter, a firm either has positive sales in both periods (with high quality) or does nothing in both (with low quality).

Note that both the separating equilibrium and the Type-III pooling equilibrium could co-exist. It would thus be intriguing to explore when both equilibria exist, which would benefit a high-quality firm more. The next result identifies the conditions for their coexistence and reveals the answer to the comparison.

Proposition 6.

(a) *When* $\theta \in [\frac{c_l}{v}, \frac{(1-\phi'(1))v+\phi'(1)c_h}{v}]$ *and* $\phi(s^{h*}) - s^{h*} > \frac{c_h - c_l}{v - c_l}$, *i.e., when the prior about product quality is intermediate and WOM is sufficiently efficient, both the Pareto-dominant separating and Type-III pooling equilibria exist.*

(b) *When both equilibria exist, the high-quality firm earns a higher equilibrium payoff in the Pareto-dominant Type-III pooling equilibrium than in the Pareto-dominant separating equilibrium.*

Proof. All proofs can be found in the Appendix. □

Proposition 6 (b) demonstrates the costly nature of the signaling mechanism. It requires that the high-quality firm bear a more significant loss ($p_1^* < c_l$) in the first period, as compared to a pooling equilibrium; the extra loss, as shown by the proposition, is not fully compensated for by the additional gain (selling to all $1 - s^*$ unserved consumers) in the second period.

The result yields important practical implications. Our analysis shows that a firm can successfully convince the market of the premium quality of its product by a deep price discount bundled with a properly chosen quantity limit for early sales. The signaling mechanism, however, comes at a substantial cost. As indicated by the result, the aggressive separating strategy requires meticulous deliberation before execution. It is a more sensible strategic choice when the seller or the product is less established and has a pessimistic market perception, i.e., when $\theta \le \frac{c_l}{v}$.

4.3. Further Discussions

We have adopted a fairly simple and stylized model in order to focus on the key elements that make the "hunger marketing" strategy work. It should be noted, however, that the main findings would continue to hold qualitatively when many of the simplifying assumptions are relaxed.

First, Milgrom and Roberts (1986) point out that (uninformative) advertising, as a form of dissipative marketing, can be a substitute for low price. By the same token, a combination of uninformative advertising and shortage can also signal high quality in our context. More generally, advertising and price can be combined strategically. In particular, any price-advertising combination that satisfies $A - (p_1 - c_l)s^{h*} = (v - c_l)\phi(s^{h*})$ can serve the purpose, where A denotes advertising expenditure. It shows that when the firm engages in a more intensive advertising campaign, it is able to reduce its downward price distortion—or even raise its price to the full-information level v. It's worth noting, however, that in the context of selling a durable good with few returning purchases, shortage—i.e., quantity limit in the first period—must be in place and made observable to consumers, as the low-quality firm can simply "cheat and run" otherwise.

Despite their substitutability on the surface as signaling instruments, low price and advertising impose different specific informational requirements for successful implementation of the signaling mechanism. When a low price is used in signaling, the firm must let consumer observe that the product is actually sold to some of them, because the loss incurred by early sales, as well as the resultant WOM, constitutes the deterrent to the low-quality firm.[19] When advertising is used, the firm must ensure that shortage is observable to consumers. To see this, note that advertising substitutes away low price, so early sales incur no loss to the firm. As a result, the low-quality firm can respond by selling to a larger number of consumers than it claims, which nullifies the signaling mechanism.

Second, it is interesting to note that shortage (supply limit) alone can be an effective signaling device when production involves a substantial fixed cost, while the price remains fixed across periods and undistorted. To see this, imagine that the high-quality firm commits to a limited supply for the first period. WOM would limit the potential demand available to the low-quality firm if it mimics, which, in turn, leads to an excessive average production cost and forces the mimicking firm to suffer a loss.

Finally, we have so far followed the tradition of the durable-good literature, assuming that the second-period price cannot be precommitted. It should be noted that our results do not change qualitatively when the price is allowed to be precommitted. In the alternative setting, the intuitive criterion can be exercised to select a unique candidate among separating equilibria, and the unique separating equilibrium coincides with the Pareto-dominant separating equilibrium identified in our main text. The predicted pooling equilibrium continues in the alternative setting. However, the intuitive criterion, as well as other standard refinement techniques, does not help eliminate pooling equilibria. Detailed analysis is available from the authors upon request.

5. Conclusion and Practical Implications

In this paper, we provide an economic rationale for the increasingly popular hunger-marketing strategy adopted by many high-tech startups in launching their flagship products, such as Xiaomi's smartphone and Pebble Technology's "first ever affordable smart watch." These firms, as new entrants to the market, are unable to leverage on established brand names and lack the trust and support of consumers, and their high-tech gadgets usually have relatively long life spans. How to convince consumers of the premium quality of a new product is challenging for these marketers, as the many strategic instruments suggested by the literature lose their bite.

[19] Shortage, even when not observable, must occur or the high-quality firm cannot get any future positive profit.

We demonstrate that hunger marketing, which involves a combination of artificially low introductory price and quantity limit, can be an effective signaling mechanism that credibly conveys hidden quality information to the market. The success of the signaling mechanism heavily relies on effective WOM to spreads early users' experiences.

Our study depicts a context that differs from previous models of quality signaling. To our best knowledge, it is among the first to explore an effective signaling device when launching a new-to-the-world durable good and to examine the role played by experiential WOM in formal modelling.

Our theoretical findings yield nontrivial practical implications by providing a useful playbook for hunger marketing in launching a new durable good.

First, our results identify a new avenue through which marketers can harness the powerful influence of WOM. Xiaomi and Pebble Technology, among many other high-tech startups, have invested heavily in online campaigns to created buzz on social media. Social media has amplified the speed and outreach of WOM enormously, which, as shown by our study, makes possible the signaling role played by the hunger marketing.

Second, WOM's catalyzing role, as revealed in our study, requires that marketers recalibrate how they measure and evaluate the influence of WOM marketing on sales accordingly. As demonstrated by our study, WOM benefits a firm not only directly as a persuasive device for purchase, but also as a (hidden) deterrent to potential mimicry.

Third, our study shows that more effective WOM, in the separating equilibrium, leads to a lower introductory price and tighter restrictions on early supply; i.e., it creates more pronounced shortage.

Finally, despite its power to convey quality information, the signaling mechanism is costly, as it requires that the high-quality firm set an artificially low price, which causes a substantial loss in the introductory period. We show that when both a separating equilibrium and a pooling equilibrium exist, the high-quality firm actually earns less profit in the former. This suggests that the aggressive separating strategy is a preferred choice when the market prior about the firm or the product is sufficiently pessimistic—e.g., when a previously unknown high-tech startup launches brand new product.

Appendix

Proof of Lemma 1

Proof. Suppose $\tilde{s}^h = 1$. Then the firm secures a profit $\left(p_1^h - c_h\right)$, which must be nonnegative, thereby requiring $p_1^h \geq c_h$. Hence, the low type must deviate to mimic it by setting $(p_1^h, 1)$, which generates strictly positive profit because $p_1^h \geq c_h > c_l$. Contradiction.

Suppose $\tilde{s}^h = 0$. In the second period, the high-quality firm has a profit $\left(p_2^h - c_h\right)\hat{s}_2(\, p_2^h \middle| (p_1^h, s^h))$. An equilibrium requires $p_2^h \geq c_h$. Hence, the low-type firm would mimic it by setting (p_1^h, s^h), which leads to no sale, and then sets a price p_2^h unless $\hat{s}_2(\, p_2^h \middle| (p_1^h, s^h)) = 0$. However, given the assumption of $p_2 \leq v$, there is no reason that a consumer, who observes $((p_1^h, s^h), p_2^h)$ refuses to buy. Hence, we conclude $\hat{s}_2(\, p_2^h \middle| (p_1^h, s^h)) > 0$. Therefore, the low-quality firm must mimic it to earn a strictly positive profit. The separating equilibrium thus dissolves.

By the definition of separating equilibria, $\Pr(t = h | p_1, s) = 1$. Consumers must be willing to buy it immediately at price $p_1 \leq p_2 \leq v$. Hence, the quantity demanded for the first period is either zero or one. Given that $\tilde{s}^h > 0$, the equilibrium must require $p_1 \leq p_2$, which further implies $\hat{s} = 1$ and, in turn, $\tilde{s}^h = s^h < 1$.

Suppose $p_2^h \leq c_h$. Because $\pi_h = \left(p_1^h - c_h\right)s^h + \left(p_2^h - c_h\right)\hat{s}_2(\, p_2^h \middle| (p_1^h, s^t)) \geq 0$, $\left(p_1^h - c_h\right)s^h$ must be nonnegative. Given $\Pr(t = h | p_1^h, s^h) = 1$ and $s^h > 0$, $p_1^h \geq c_h$. Hence, the low type must have an incentive to mimic it, which allows it to receive strictly positive profit given its low cost c_l. Contradiction.

By the argument laid out above, in a sensible separating equilibrium, the high-quality firm earns a positive profit $p_2^h - c_h > 0$ from each unit of sale. By the argument above, $\hat{s}_2(\, p_2^h \middle| (p_1^h, s^h)) > 0$, the firm must be able to sell to all unserved consumers. □

Proof of Proposition 1

Proof. Part (a) is straightforward. Given the proposed belief, the low-quality firm has no incentive to mimic $((p_1^{h*}, s^{h*}); p_2^{h*})$, as conditions (5), (3), and (6) suggest.

We now verify the two claims in part (b).

Claim 1 $p_1^{h*} \leq c_l \leq c_h < p_2^{h*}$. By Lemma 1, $c_l \leq c_h < p_2^{h*}$. We then verify $p_1^{h*} < c_l$. Suppose otherwise $p_1^{h*} \geq c_l$. Then if the low-quality firm mimics its high-quality counterpart, it receives a nonnegative profit in the first period. By Lemma 1, $\tilde{s}^{h*} < 1$, so a fraction of consumers with a mass $1 - \phi(\tilde{s}^{h*})$ would still believe the product is of high quality if the firm sets a price p_2^{h*}, which, again, leads to a positive profit in the second period. Then the low-quality firm must deviate.

Claim 2 $s^{h*} < \hat{s}(p_1^{h*}, s^{h*}) = 1$. In the equilibrium, $p_2^{h*} > p_1^{h*}$. Hence, consumers must be willing to purchase it at price p_1^{h*} instead of waiting until the next period given their belief of $\Pr(t = h | p_1^{h*}, s^{h*}) = 1$ and the expectation of p_2^{h*}. □

Proof of Proposition 2

Proof. The constraint $(p_1 - c_l)s + (p_2 - c_l)(1 - \phi(s)) \le 0$ must be binding, because otherwise a more profitable equilibrium for the high-quality firm can be achieved by raising p_1. The maximization problem can thus be rewritten as

$$\max_{(p_1,s);p_2} (p_2 - c_l)\phi(s) - (p_2 - c_l)s - (c_h - c_l).$$

First-order conditions yield

$$p_2^{h*} = v, s^{h*} = \arg\max_{s\in(0,1)} \{\phi(s) - s\} < 1,$$

and the second-order condition is satisfied because $(v - c_l)\phi''(s) < 0$. With a binding constraint, the introductory price is uniquely determined as

$$p_1^{h*} = c_l - (v - c_l)\left(\frac{1 - \phi\left(s^{h*}\right)}{s^{h*}}\right) \le c_l.$$

We now turn to its existence. Separating equilibrium occurs only if the high-quality firm gets positive profits, i.e.,

$$\begin{aligned}\bar{\Pi}^S &= \left(p_1^{h*} - c_h\right)s^{h*} + (v - c_h)\left(1 - s^{h*}\right)\\ &= \left(c_l - (v - c_l)\left(\frac{1 - \phi\left(s^{h*}\right)}{s^{h*}}\right) - c_h\right)s^{h*} + (v - c_h)\left(1 - s^{h*}\right)\\ &= \left(\phi\left(s^{h*}\right) - s^{h*}\right)(v - c_l) - (c_h - c_l) > 0.\end{aligned}$$

Note that $\phi\left(s^{h*}\right) - s^{h*} = \max_{s\in(0,1)} \{\phi(s) - s\}$. Hence if $\phi(\tilde{s}) > \eta(\tilde{s})$for all $\tilde{s} \in (0, 1)$ and a separating equilibrium exists under η, then a separating equilibrium must exist under ϕ. □

Proof of Proposition 3

Proof. Let us consider the signaling cost $\psi = (v - p_1^{h*})s^{h*}$.

$$\begin{aligned}\psi(\phi) &= \left[v - c_l + (v - c_l)\left(\frac{1 - \phi\left(s^{h*}(\phi)\right)}{s^{h*}(\phi)}\right)\right]s^{h*}(\phi)\\ &= (v - c_l)\left[1 - \phi\left(s^{h*}(\phi)\right) + s^{h*}(\phi)\right]\\ &= (v - c_l)(1 - \max(\phi(s) - s))\\ &< (v - c_l)(1 - \max(\eta(s) - s))\\ &= \psi(\eta).\end{aligned}$$

□

Proof of Proposition 4

Proof. Simple math gives $p_1^{h*} = c_l - (v - c_l)\frac{\alpha^{\frac{\alpha}{\alpha-1}} - 1}{\alpha}$.

$$\frac{dp_1^{h*}}{d\alpha} = -\frac{d\frac{\alpha^{\frac{\alpha}{\alpha-1}} - 1}{\alpha}}{d\alpha} = -\frac{1}{\alpha^2}\left[\frac{\alpha}{\alpha - 1}\alpha^{\frac{\alpha}{\alpha-1}}\left(1 - \frac{\ln\alpha}{\alpha - 1}\right) - \alpha^{\frac{\alpha}{\alpha-1}} + 1\right]$$

Note that

$$\lim_{\alpha\to 0} \frac{\alpha}{\alpha - 1}\alpha^{\frac{\alpha}{\alpha-1}}\left(1 - \frac{\ln\alpha}{\alpha - 1}\right) - \alpha^{\frac{\alpha}{\alpha-1}} + 1 = 0,$$

and

$$\frac{\partial\left(\frac{\alpha}{\alpha-1}\alpha^{\frac{\alpha}{\alpha-1}}\left(1 - \frac{\ln\alpha}{\alpha-1}\right) - \alpha^{\frac{\alpha}{\alpha-1}} + 1\right)}{\partial\alpha} = \frac{\alpha^{\frac{\alpha}{\alpha-1}}}{(\alpha - 1)^4}\left(\alpha\ln^2\alpha - (\alpha - 1)^2\right) < 0.$$

Hence $\frac{\alpha}{\alpha-1}\alpha^{\frac{\alpha}{\alpha-1}}\left(1 - \frac{\ln\alpha}{\alpha-1}\right) - \alpha^{\frac{\alpha}{\alpha-1}} + 1 < 0$, which implies that $\frac{dp_1^{h*}}{d\alpha} > 0$.

The high-quality firm's quantity $s^{h*} = \alpha^{\frac{1}{1-\alpha}}$.

$$\frac{ds^{h*}}{d\alpha} = \frac{d\alpha^{\frac{1}{1-\alpha}}}{d\alpha} = \frac{\alpha^{\frac{\alpha}{1-\alpha}}}{(\alpha-1)^2}(\alpha\ln\alpha - \alpha + 1) > 0.$$

The share of informed consumers is $(s^{h*})^\alpha = \alpha^{\frac{\alpha}{1-\alpha}}$. Evaluating it with respect to α

$$\frac{d(s^{h*})^\alpha}{d\alpha} = \frac{d(\alpha^{\frac{\alpha}{1-\alpha}})}{d\alpha} = \frac{\alpha^{\frac{\alpha}{1-\alpha}}}{(\alpha-1)^2}(\ln\alpha - \alpha + 1) < 0.$$

□

Proof of Proposition 5

Proof. It should be noted that as consumers make binary purchase decision, quantity demanded in the first period, $\hat{s}$, is either zero or one. Hence, $s = \tilde{s}$. Hence, in the equilibrium, the low-quality firm earns a profit $\pi_l = (p_1 - c_l)s$, and the high-quality one makes $\pi_h = (p_1 - c_h)s + (p_2 - c_h)(\phi(s) - s)$.

It is thus straightforward to see that given the constraints of $p_1 \le \theta v$, we must have $p_1 = \theta v$, as price choices do not affect quantity choice in search for Pareto-dominant equilibrium.

To find this equilibrium, we consider the payoff function for the high type

$$\pi_h = (\theta v - c_h)s + (v - c_h)(\phi(s) - s).$$

Evaluating it with respect to s yields

$$\begin{aligned}\frac{d\pi_h}{ds} &= (\theta v - c_h) + (v - c_h)\big(\phi'(s) - 1\big)\\ &= \phi'(s)(v - c_h) - (1-\theta)v.\end{aligned}$$

Hence, π_h is maximized by s^* where $\phi'(s^*) = \frac{(1-\theta)v}{v-c_h}$, which is strictly less than 1 when $\theta < \frac{(1-\phi'(1))v+\phi'(1)c_h}{v}$ holds. π_h strictly increases with s for $s < s^*$ and decreases with it once s exceeds this cutoff. Further, the low-quality firm's profit strictly increases with s. Hence, setting $s = s^*$ constitutes the Pareto optimum.

In the equilibrium, the high-quality firm earns a profit

$$\begin{aligned}\pi_h^* &= (\theta v - c_h)s^* + (v - c_h)(\phi(s^*) - s^*)\\ &= \phi(s^*)(v - c_h) - s^*(1-\theta)v > \phi(0)(v - c_h) - 0 = 0.\end{aligned}$$

□

Proof of Proposition 6

Proof. To prove the second part, recall by the proof of Proposition 2 that the Pareto-dominant separating equilibrium maximizes the following

$$\begin{aligned}\pi_h^S &= \max_s\,(v - c_l)\phi(s) - (v - c_l)s - (c_h - c_l)\\ &= \max_s\,(v - c_h)(\phi(s) - s) - (c_h - c_l)(1 - \phi(s) + s),\end{aligned}$$

where the superscript S refers to separating equilibrium. In contrast, the Pareto-dominant Type-III pooling equilibrium maximizes

$$\pi_h^P = \max_s\,(v - c_h)(\phi(s) - s) - (c_h - \theta v)s,$$

where the superscript P refers to pooling equilibrium. Because $\theta v > c_l$ and $1 - \phi(s) > 0$, it follows that $\pi_h^S < \pi_h^P$ for every given s. Note that the proof requires $c_h \ge c_l$. □

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijindorg.2020.102621.

CRediT authorship contribution statement

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