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PRODUCT DEVELOPMENT CAPABILITY AND MARKETING STRATEGY FOR NEW DURABLE PRODUCTS

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Abstract

Product development capability and marketing strategy for new durable products

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Our objective is to understand how a firm's product development capability (PDC) affects the launch strategy for a durable product that is sequentially improved over time in a market where consumers have heterogeneous valuations for quality. We show that the launch strategy of firms is affected by the degree to which consumers think ahead. However, only the strategy of firms with high PDC is affected by the observability of quality. When consumers are myopic and quality is observable, both high and low PDC firms use price skimming and restrict sales of the first generation to consumers with high willingness to pay (WTP). A high PDC firm, however, sells the second generation broadly while a low PDC firm only sells the second generation to consumers with low WTP. When consumers are myopic and quality is unobservable, a firm with high PDC signals its quality by offering a low price for the first generation, which results in broad selling. The price of the second generation is set such that only high WTP consumers buy. A firm with low PDC will not mimic this strategy. If a low PDC firm sells the first generation broadly, it cannot discriminate between the high and low WTP consumers. When consumers are forward looking, a firm with high PDC sells the first generation broadly. This mitigates the "Coase problem" created by consumers thinking ahead. It then sells the second generation product only to the high WTP consumers. In contrast, a firm with low PDC does the opposite. It only sells the first generation to high WTP consumers and the second generation broadly.

Keywords: Product development, marketing strategy, durable goods, quality, signaling game

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1   Introduction

The quality of a product that provides unique value to consumers is often affected by the firm's product development capability. In some cases, firms that introduce new consumer electronics and appliances such as digital photo frames, specialized equipment, software, or high-end sporting goods have a well-known track record of introducing improved versions of their products over time. In other cases, firms are either unknown or have made limited improvements to products that have been in the market for a relatively long time.

Consider the evolution of the video game console market in the 1990s. In 1994, Sony entered the market and became the market leader with Playstation (PS) and followed it with the even more successful Playstation 2 (PS2) in 2000. PS2 offered improved user benefits such as internet connectivity and an inclusive DVD player (see for example, Ofek 2008). Because Sony was new to the video console market, it is possible that purchasers of the first Playstation may not have foreseen the launch and benefits of PS2 when making the decision to buy PS.

In contrast, the launch of successive products in some markets is more predictable. Here, it is likely that consumers account for the potential benefits of future products when making a purchase decision. For example, since the launch of Apple's widely successful iPod in 2001, new and improved versions of this product have been introduced with great regularity offering better storage, higher song capacity, improved screens, and functionality such as video and touch.[1]

When a firm develops new product versions by improving quality or performance over time, sales of a first (early) generation product often hinder the profitability of subsequent versions. Consumers who buy the first generation product will have lower willingness to pay (WTP) for a new generation of the same product because they already have a functioning product. Accordingly, a supplier is restricted to charging existing consumers a maximum price equal to the incremental value of the new generation. This means that high performing early generation products limit the price that can be charged for subsequent generations.[2] When launching the first product, the firm therefore faces the choice of employing price

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[1]See, for example, the online features "Evolution of a Blockbuster"(http://online.wsj.com/public/ resources/documents/info-ipod0709.html, retrieved on 31 July 2011) and "The New iPods" (http://online.wsj.com/public/resources/documents/info-ipodcompare0709.html, retrieved on 31 July 2011).

[2]This is also the basis for the Coase problem whereby a durable good monopolist is not able to implement time-based discrimination due to customers' understanding that the price will drop over time (Coase 1972).

skimming (i.e., charging a high price and selling to a limited number of consumers with high WTP) or price penetration (i.e., selling the product to a broad set of consumers including those with low WTP). Price penetration may restrict the ability to charge higher prices for second generation products because most potential buyers already have a first generation product. We use the term "target breadth" as a shorthand to describe the marketer's choice of price skimming or price penetration described above.

To analyze how marketing strategy (i.e., the pricing of unique products over time) is affected by the firm's product development capability (PDC), we propose a simple model. A model with two periods is the simplest way to represent firm dynamics in a context where the first generation of a product is improved upon through product development. We restrict the firm decisions to pricing for the first and second generation products, and the level of investment in product development at the end of the first period to improve the product for the second period. These constitute the most parsimonious set of decisions that can be used to understand how marketing strategies (the pricing of products over time) are affected by PDC.

We also examine how the firm's strategy is affected by environmental factors such as how "deeply" (i.e., how far ahead) consumers think about the purchase and also how easy it is for consumers to assess the quality of products prior to purchase. In economics, unobserved quality is an important cause of market failure: it is the basis for substantial literature including Akerlof (1970). We analyze how the firm responds when it faces a problem of adverse selection, i.e., it has high quality but consumers may not be willing to pay for high quality because they cannot be sure that the product is, in fact, high quality. In particular, we examine whether the firm will simply charge a price based on the expected value of the product or attempt to signal its high quality to consumers through actions. The objectives of the paper can be summarized as follows:

a) How does a firm's PDC affect its introductory marketing strategy in terms of pricing (which determines the "target breadth") and its investment in product improvement when consumers are either myopic (they consider only the current benefits offered by the product) or forward looking (they consider the expected value of the product in the future as well)?

b) How are a firm's launch strategies affected when consumers cannot assess product qual-

ity by inspection?

The key findings of our analysis are:

1. A firm with high PDC sets prices so that it sells both the first and second generation products to consumers with a high WTP. In contrast, a firm with low PDC focuses on intertemporal price discrimination and sells to each consumer type only once.

2. We show that unobservability of quality changes the strategy of a firm with high PDC because it will signal its quality by implementing penetration pricing (a strategy that a firm with low PDC finds unattractive). This leads to the unusual observation that the first generation of a high quality product is sometimes priced lower than the first generation of a low quality product!

3. We show that when consumers are forward-looking the launch strategies of firms change independent of their PDC. The change in strategy is driven by a reduced WTP of consumers for the first generation product.

Interestingly, the market strategies employed by a firm with high PDC when quality is not observable or when consumers are forward looking are identical: market penetration in period 1 and sell only to high WTP consumers in period 2. But the reasons for adopting "market penetration in period 1 and restricting sales to high WTP consumers in period 2" are very different. In the former case, it is the firm's desire to signal its quality that leads to the lower introductory price. In the latter case, it is consumers' lower WTP that leads to the lower introductory price.

The rest of the paper is organized as follows. Section 2 provides a brief literature review. In Section 3 we present a model of a monopolist selling to two types of myopic consumers. In Section 4, we first present the optimal strategies of the firm when quality is observable and then when it is unobservable. Similarly in Section 5, we first present the model for forward-looking consumers when quality is observable and then when it is unobservable.

2   Literature Review

In many categories, new product generations appear on a regular basis. Nevertheless, research (e.g., Abernathy and Utterback 1978) suggests that technological constraints and uncertainty

inhibit the willingness of firms to introduce new generations. With uncertainty, a sequential strategy is both "information yielding" compared to an all-or-nothing crash program (Weitzman et al 1981) and beneficial in a context of network externality (Padmanabhan et al 1997, Ellison and Fudenberg 2000). These benefits, however, are balanced by the reluctance of consumers to trade up to a new generation (with higher marginal costs) when they already possess a functional first generation product. Another factor driving sequential generations of products is competition, either in R&D ("R&D races") or in markets.

On the one hand, incumbent firms may invest more than entrants in R&D for subsequent innovations due to intellectual property rights and the diffusion of new products (Banerjee and Sarvary 2009). On the other hand, prior success in R&D allows firms to gain reputation. Firms therefore trade-off R&D investment with reputation building (Ofek and Sarvary 2003). In the absence of intellectual property rights, the possible entry of imitators may also drive incumbents to invest in developing a higher quality of new products (Purohit 1994). Our research examines why a firm with market power may develop new generations in the complete absence of competitive threats. Our objective is to show how the launch and targeting strategies are affected by three factors: the PDC of the firm, the observability of product quality, and the degree to which consumers think ahead when making a current purchase decision.

Our research is also related to the durable goods literature which is reviewed by Waldman (2003). Generally, the durable goods literature focuses on the effect of secondhand markets, the role of commitment to future price (or quality), and adverse selection between new and used goods. Recently, the literature has examined the role of pricing in markets where new products are launched in a context of old (or used) products. This work highlights a Coasian time inconsistency problem because of which, the monopoly price for a current product is lower due to the expected launch of products in the future. A firm may therefore offer lower quality of a current product to credibly commit to price and quality in the future (Dhebar 1994). Similarly, Moorthy and Png (1992) show that a monopolist should launch a high quality product before launching a low quality product. The firm may, however, face difficulties in developing a high quality product first because a better performing product often requires additional R&D (Langinier 2005). Moreover, the monopolist may want to sell a higher quality product later if it does not discriminate between past and new buyers (Kornish 2001). In fact, when the past buyers can be identified, a monopolist can price

discriminate when launching a new product by either producing more of the older product, offering upgrade prices to past buyers, or buying back excess stock of the older product (Fudenberg and Tirole 1998). We extend this literature by treating quality as an endogenous decision. This reflects the idea that better performing versions of a product become available for launch after significant investment in R&D. We also examine how the ability to develop quality affects a firm's decision to target and "trade up" different consumer segments.[3] Other reasons why a monopolist might offer upgrades to an existing product include market growth (Ellison and Fudenberg 2000) and the management of time inconsistency (Shankaranarayanan 2007, Coase 1972). In contrast to our work, this stream of literature deals with network externalities and exogenous quality.

Research in operations management considers the effect of product design on upgrade timing (Krishnan and Zhu 2006). If improvements relate to inter-operable components of an overall product and are separable, firms should launch product "upgrades" frequently (Ramachandran and Krishnan 2008). Our research does not deal with the interoperability of components; our intent is to examine products with unique functionality that can be improved through investments in product development. In a market where the demand depends on durability and obsolescence, the provision of a single period "product life" as a design aspect has also been analyzed in the marketing literature (Koenigsberg et al 2011). We address the challenge faced by a firm that introduces upgraded versions of its product over time and with the goal to understand the impact of PDC on marketing strategy (i.e., choice of target segment and pricing). This is a new question. We therefore abstract away from the aspects of product design and technology to concentrate on the effect of overall investment on product performance and a consumer's willingness to trade up.

Information asymmetry regarding product quality has been an important area of research for durable products (Waldman 2003). Hendel and Lizzeri (1999) analyze the "Lemons' problem" (Akerlof 1970) and show that information asymmetry can result in lower levels of trade in secondhand markets. We consider information asymmetry in the absence of secondhand markets. In a related article, Balachander and Srinivasan (1994) analyze a monopolist's ability to signal competitive advantage to a potential entrant in a market where demand across periods is not linked. In contrast, the recipients of the signal in our model are consumers

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[3]Our focus is on categories such as consumer electronics where the secondhand market does not have a significant effect. Yin et al 2010 focus on markets where this is not the case.

who are uncertain about product quality. In addition, the interaction of demands from one period to the next is a key aspect of the model we consider.

Our analysis combines supply-side product development and demand-side consumer heterogeneity to understand how PDC influences a firm's marketing strategy. In sum, the analysis demonstrates that the choice of marketing strategy is highly sensitive to the PDC of the firm, the thinking process of consumers, and the observability of quality.

The following section presents the model followed by the key findings.

3 The Model

We consider a monopolist firm and a heterogeneous market over two periods $t = 1, 2$. The firm sells a product of quality q_1 in period 1 and q_2 in period 2 where $q_2 = q_1 + \Delta q$. The prices in each period are denoted by p_t (where $t = 1, 2$).

3.1 Consumer Utility

At the end of period 1, the firm can improve the quality of the product so that the second period product is better. The market consists of two types of consumers with taste for quality $\theta_i \; \forall \; i \in \{L, H\}$ with segment sizes $1 - \lambda$ of "Highs", type H, who place a higher value on quality and $\lambda \in [0, 1]$ of "Lows", who place a lower value on quality ($\theta_H > \theta_L$). A consumer's decision in period 1 consists of choosing between a) buying now b) waiting to buy in period 2 or c) not buying at all. As will be explained shortly, we focus on situations where the firm services both segments of consumers at least once. Accordingly, the first period decision boils down to buying now or waiting until period 2. When the consumer buys in period 1 she derives a surplus given by $\theta_i q_1 - p_1 + \delta \theta_i q_1$ where $\delta \theta_i q_1$ is the residual surplus in period 2, and δ is the common discount factor. On the other hand, if she waits to buy the product in period 2, she derives a surplus of $\delta (\theta_i q_2 - p_2)$. Consumer utility can then be written as $u_1 = \max\{\theta_i q_1 - p_1 + \delta \theta_i q_1, \delta (\theta_i q_2 - p_2)\}$. When consumers are forward looking and $\delta > 0$, consumers are assumed to have rational expectations about the quality and price of the second period product. Conversely, by setting $\delta = 0$ in the utility function, we represent "myopia" on the part of consumers, i.e., they think only about the present when making decisions.

To represent the consumer's decision to buy in period 1, we define an indicator function $I_{\theta i} = 1$ if a consumer of type θ_i buys in period 1 and zero otherwise. Similarly, the indicator function for the second period $J_{\theta i} = 1$ if a consumer of type θ_i buys in period 2 and zero

otherwise. Summarizing, we obtain

$$I_{\theta i} = \begin{cases} 1 \text{ if } u_1 = \theta_i q_1 - p_1 + \delta\theta_i q_1 - \delta\left(\theta_i q_2 - p_2\right) \geq 0 \\ 0 \text{ otherwise.} \end{cases}$$

$$J_{\theta i} = \begin{cases} 1 \text{ if } u_2 = \theta_i\left[\left(1 - I_{\theta_i}\right)q_1 + \Delta q\right] - p_2 \geq 0 \\ 0 \text{ otherwise.} \end{cases}$$

Notice that a consumer who purchased in period 1 ($I_{\theta_i} = 1$) receives a residual utility of $\theta_i q_1$ from the first period product in Period 2. However, she can also buy the second generation product in Period 2 and will do so if the marginal utility is positive, i.e., if $\theta_i\left[\left(1 - I_{\theta_i}\right)q_1 + \Delta q\right] - p_2 = \theta_i\Delta q - p_2 > 0$.

To simplify the exposition, we assume $\theta_H = 1$ and $\theta_L = \theta < 1$. To focus on the interesting case where firms are torn between a) charging a high price and not serving Lows or b) charging a low price and leaving the Highs' premium on the table, we impose an upper bound on λ (the fraction of the market that is Lows'). When the Lows segment is either too large or too attractive, a supplier will mass market the product every period and treat the market as being comprised entirely of Lows. The following bound for λ is derived in the Appendix.

$$\lambda < 1 - \theta. \tag{1}$$

In addition, the context is only interesting if the Lows are worth serving independent of the PDC of the firm. In particular, if the WTP of Lows is too low, then the market is *de facto* homogeneous composed of only the Highs. This would render the question of price skimming or price penetration irrelevant. Accordingly, we restrict our attention to conditions where both Highs and Lows are served at least once across the two periods. To ensure that Lows are worth serving, the second period surplus created by a quality increase Δq for the Highs must be *less* than the total surplus created by selling to the Lows for the first time. This condition is (see Appendix):

$$\theta\left(q_1 + \Delta q\right) > \Delta q \Leftrightarrow q_1 > \frac{1 - \theta}{\theta}\Delta q. \tag{2}$$

When this condition is violated, the firm may develop sufficient quality in period 2 such that it pays to "ignore" the Lows. In sum, we focus on the situation where profits from both types of consumers are strategically important. Equations 1 and 2 together are sufficient to ensure that both types of consumers are served at least once in the two periods.

3.2 Market Demand and Firm Profits

The market consists of unitary aggregate demand. The demand in period 1 is given by:

$$D_1 = \lambda I_\theta + (1 - \lambda) I_1. \tag{3}$$

Since consumers are homogeneous except for their type (θ_i), either all the Lows $(\theta_i = \theta)$ buy $(I_\theta = 1$ if $u_1 (\theta_i = \theta) \geq 0$ resulting in demand $\lambda)$ or not buy $(I_\theta = 0$ resulting in no demand). Similarly, either all the Highs $(\theta_i = 1)$ buy $(I_1 = 1$ if $u_1 (\theta_i = 1) \geq 0$ resulting in demand $1 - \lambda)$ or not buy $(I_1 = 0$ resulting in no demand). Note that because $\theta < 1$, if $I_\theta = 1$ then $I_1 = 1$. The demand in period 2 is given by

$$D_2 = \lambda J_\theta + (1 - \lambda) J_1. \tag{4}$$

As before, either all the Lows buy $(J_\theta = 1$ resulting in demand $\lambda)$ in period 2 or not buy $(J_\theta = 0$ resulting in no demand). Similarly, either all the Highs buy $(J_1 = 1$ resulting in demand $1 - \lambda)$ or not buy $(J_1 = 0$ resulting in no demand).

The consumers and the firm are risk-neutral and have a common discount factor δ (except in the case of myopic consumers). We assume that there is no after-market for previous generation products, and they are disposed of at zero cost when a new generation is purchased. The firm invests in product development at the beginning of period 2. Accordingly, total profits are given by

$$\pi = (p_1 - c_1) D_1 + \delta (p_2 - c_2) D_2 - C (\Delta q) \text{ where } C (\Delta q) = \frac{\Delta q^2 + 2\beta q_1 \Delta q}{2\alpha}. \tag{5}$$

Here, $C (\Delta q)$ is the cost of developing an improvement in quality of Δq and α reflects the firm's PDC $(\alpha > 0)$. The parameter β is the technological cost factor. It is positive when the cost of product development increases as the existing quality q_1 approaches a technological frontier. As a simplification, we assume that the firm's level of investment in product development becomes common knowledge at the end of period 1. This is reasonable when consumers learn about the firm's product development capability from their interaction in period 1. Rational expectations imply that consumers correctly infer the profit maximizing quality increase.

The marginal cost $c_2 = c_1 + \rho \Delta q$ (where $\rho \in [0, \theta]$) increases in proportion to the quality developed (Δq) and $c_1 = c.$[4] Further, without loss of generality we assume $c = 0.$[5] As a

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[4]The upper limit on ρ is necessary for the firm to have incentive to improve quality for period 2 even if it were to target only the low WTP customers. See Proof of Proposition 1 in the Appendix.

[5]This assumption is used only for the ease of exposition. The qualitative results extend also to cases where $c > 0$.

result, the firm's profit across two periods is written as:

$$\pi = p_1 D_1 + \delta \left[(p_2 - \rho \Delta q) D_2 - \frac{\Delta q^2 + 2\beta q_1 \Delta q}{2\alpha} \right]. \tag{6}$$

The parameters ρ (the factor for marginal cost increase in period 2) and δ (the discount factor) are assumed to be common knowledge. Note that this framework can be extended to the case when the outcome of product development or R&D is uncertain.[6]

4 Consumers are Myopic

We first consider "myopic" consumers who maximize utility in each period and do not consider the future. This may be a reasonable representation of consumer behavior when either the firm's PDC or its plans are unknown. On the one hand, Playstation marked Sony's entry into the market for video game consoles. At the time of the launch, consumers focussed on the immediate incremental benefits of the Playstation. In situations such as this, buyers are less likely to assess the benefits of a "theoretical" next generation when buying the first product. On the other hand, consumers develop rational expectations about future generations of products when firms have a "history" of introducing improved versions over time. For example, consumers are likely to develop expectations about future generations of iPods and iPhones over time based on the historical frequency of upgrades introduced by Apple. We analyze the latter situation by considering forward-looking consumers in Section 5.

4.1 Quality is Observable

We first examine the case when consumers can observe firm type. This case is a helpful benchmark to understand how asymmetric information affects the market. When quality is observable, myopic consumers buy whenever they obtain a positive net surplus by buying and using the new product.

The first period utility of the two types of myopic consumers are given by the utility

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[6]For example, the model is extendable to a game where the probability of successfully developing a quality Δq having invested $C(\Delta q)$ in R&D is given by $\Pr(\Delta q) = 1 - \zeta \Delta q$ where $\zeta > 0$ is the difficulty faced by the firm to develop the quality improvement Δq. In the current setup, the parameter $\zeta > 0$ has multiple values to reflect heterogeneity in the product development capability of firms.

functions

$$u_1\left(\theta_i = \theta\right) \;=\; \theta q_1 - p_1 \text{ for Lows,}$$
$$u_1\left(\theta_i = 1\right) \;=\; q_1 - p_1 \text{ for Highs.} \tag{7}$$

Similarly, utility of buying the product for the first time in period 2 for Lows and Highs are respectively given by $\theta\left(q_1 + \Delta q\right) - p_2$ and $q_1 + \Delta q - p_2$. However, because a consumer who purchased in period 1 receives a residual utility of θq_1 (or q_1) from the product she owns, the marginal utility of purchasing in period 2 is $\theta\Delta q - p_2$ or $\Delta q - p_2$. Therefore, with the indicator functions I_θ and I_1, the second period utilities of a Lows and Highs are written as:

$$u_2\left(\theta_i = \theta\right) = \theta\left[\left(1 - I_\theta\right)q_1 + \Delta q\right] - p_2 \text{ for Lows,}$$
$$u_2\left(\theta_i = 1\right) = \left(1 - I_1\right)q_1 + \Delta q - p_2 \text{ for Highs.} \tag{8}$$

Here $I_\theta = \begin{cases} 1 \text{ if } \theta q_1 - p_1 \geq 0 \\ 0 \text{ otherwise} \end{cases}$ and $I_1 = \begin{cases} 1 \text{ if } q_1 - p_1 \geq 0 \\ 0 \text{ otherwise} \end{cases}$. Similarly, we use the indicator function J to capture the consumer's decision to buy in period 2:

$$J_\theta = \begin{cases} 1 \text{ if } \theta\left(q_1 + \Delta q\right) - p_2 \geq \theta q_1 I_\theta \\ 0 \text{ otherwise} \end{cases} \quad \text{and } J_1 = \begin{cases} 1 \text{ if } q_1 + \Delta q - p_2 \geq q_1 I_1 \\ 0 \text{ otherwise.} \end{cases}$$

Extensive Form of the Game: The game we analyze has two stages:

Stage 1 The firm chooses the price p_1 for the first period product, and consumers evaluate the offer made by the firm based on the quality q_1.

Stage 2 At the beginning of period 2 $(t = 2)$, the firm invests in product development to deliver a quality improvement Δq. Both the investment and the developed quality are observable to consumers. The firm offers a price p_2 for the second period product, following which consumers decide whether or not to buy.

As noted earlier, we consider a market where both types of consumers are served at least once (i.e., $I_\theta + I_1 > 0$ and $J_\theta + J_1 > 0$) and the firm sells in both periods (i.e., $I_\theta + J_\theta > 0$ and $I_1 + J_1 > 0$). The firm maximizes the objective function $\max_{p_1, p_2, \Delta q} \pi$ where π is given by equation 6. There are four possible market outcomes where both types of consumers are served at least once and the firm sells in both periods. Each outcome is associated with specific values of D_1 and D_2 and a set of constraints which are as follows.[7]

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[7]See Figure 3 in the Appendix.

a) *Market penetration*: Both segments buy in period 1 ($I_\theta = 1, I_1 = 1$) but only the Highs buy in period 2 ($J_\theta = 0, J_1 = 1$) under the following conditions (or "pricing constraints") $p_1 \leq \theta q_1$ and $\theta \Delta q < p_2 \leq \Delta q$.[8] The firm decision problem is therefore given by

$$\pi_{MP} = \max_{p_1, p_2, \Delta q} \pi \text{ s.t. } \theta q_1 - p_1 \geq 0, \text{ and } \Delta q - p_2 \geq 0. \tag{9}$$

b) *High-end focus and then mass market*: The Highs buy in period 1 ($I_\theta = 0, I_1 = 1$) but both segments buy in period 2 ($J_\theta = 1, J_1 = 1$) under the conditions $\theta q_1 < p_1 \leq q_1$ and $p_2 \leq \Delta q < \theta (q_1 + \Delta q)$.[9] The firm decision problem is therefore given by

$$\pi_{HF} = \max_{p_1, p_2, \Delta q} \pi \text{ s.t. } q_1 - p_1 \geq 0, \text{ and } \Delta q - p_2 \geq 0. \tag{10}$$

c) *Market inversion*: The Highs buy in period 1 ($I_\theta = 0, I_1 = 1$) and the Lows buy in period 2 ($J_\theta = 1, J_1 = 0$) under the conditions $\theta q_1 < p_1 \leq q_1$ and $\Delta q < p_2 \leq \theta (q_1 + \Delta q)$. The firm decision problem is therefore given by

$$\pi_{MI} = \max_{p_1, p_2, \Delta q} \pi \text{ s.t. } q_1 - p_1 \geq 0, \text{ and } \theta (q_1 + \Delta q) - p_2 \geq 0. \tag{11}$$

d) *Mass market*: Both segments buy in both periods ($I_\theta = 1, I_1 = 1, J_\theta = 1, J_1 = 1$). The conditions are $p_1 \leq \theta q_1$ and $p_2 \leq \theta \Delta q$. The firm decision problem is therefore given by

$$\pi_{MM} = \max_{p_1, p_2, \Delta q} \pi \text{ s.t. } \theta q_1 - p_1 \geq 0, \text{ and } \theta \Delta q - p_2 \geq 0. \tag{12}$$

Table 1 below summarizes the above.

Table 1: Firm Strategies, Consumer Decisions, Demands and Pricing

	Consumer decisions		Demands	Pricing constraints
	Lows	Highs		
Market penetration	Period 1: $I_\theta = 1$	$I_1 = 1$	1	$p_1 \leq \theta q_1$ and
	Period 2: $J_\theta = 0$	$J_1 = 1$	$1 - \lambda$	$\theta \Delta q < p_2 \leq \Delta q$
High-end focus and then mass market	Period 1: $I_\theta = 0$	$I_1 = 1$	$1 - \lambda$	$\theta q_1 < p_1 \leq q_1$ and
	Period 2: $J_\theta = 1$	$J_1 = 1$	1	$p_2 \leq \Delta q < \theta (q_1 + \Delta q)$
Market inversion	Period 1: $I_\theta = 0$	$I_1 = 1$	$1 - \lambda$	$\theta q_1 < p_1 \leq q_1$ and
	Period 2: $J_\theta = 1$	$J_1 = 0$	λ	$\Delta q < p_2 \leq \theta (q_1 + \Delta q)$
Mass market	Period 1: $I_\theta = 1$	$I_1 = 1$	1	$p_1 \leq \theta q_1$ and
	Period 2: $J_\theta = 1$	$J_1 = 1$	1	$p_2 \leq \theta \Delta q$

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[8] Notice that since $\theta < 1$, $p_1 \leq \theta q_1 < q_1$ implies that $p_1 \leq \theta q_1$ is a sufficient condition for both Highs and Lows to buy the product. Similarly, $\Delta q > \theta \Delta q$ implies if $\theta \Delta q < p_2 \leq \Delta q$, only the Highs buy (i.e., trade up) in period 2 leading to market penetration (i.e., both Highs and Lows buy in period 1, but only the Highs buy in period 2).

[9] Notice that if only the Highs buy in period 1 and they trade up in period 2, from equation 2, $p_2 \leq \Delta q < \theta (q_1 + \Delta q)$ implies that both segments buy in period 2.

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We now solve the firm's constrained optimization problem for each of the decision alternatives and then compare the profit values across the alternatives. Note that the optimal marketing strategies depend on the firm's level of PDC. Proposition 1 describes the optimal strategies of the firm as a function of α, the firm's PDC. Please refer to the appendix for all proofs.

Proposition 1 *Myopic Consumers: Under complete information, a firm having PDC higher than a threshold ($\alpha \geq \hat{\alpha}_M$ where $\hat{\alpha}_M = \frac{2q_1}{1-\rho+\lambda(\theta-\rho)} \left(\frac{\lambda\theta}{1-\rho-\lambda(\theta-\rho)} + \beta \right)$) serves the Highs in both periods and the Lows in period 2 (***"High-end focus and then mass market"*** strategy). A firm having PDC lower than the threshold $\alpha < \hat{\alpha}_M$ serves only the Highs in period 1 and only the Lows in period 2 (***"Market inversion"*** strategy).*

Proposition 1 demonstrates that the PDC of the firm has a significant influence on its optimal marketing strategy: the price and the segment(s) it targets. A firm with high PDC ($\alpha \geq \hat{\alpha}_M$) can develop higher quality at a lower cost than a firm with low PDC ($\alpha < \hat{\alpha}_M$).[10] In fact, the firm can profitably develop the next generation with a price/quality offer such that the Highs trade up. In period 2, this type of firm therefore, sells the new generation product to both Highs and Lows. We call this a "high-end focus and then mass market" strategy. Note that both Highs and Lows use state-of-the-art technology in period 2. A firm with high PDC develops a quality and charges a price that optimizes profits from second period sales to both Highs and Lows, the reservation price being equal to the WTP of the Highs. Nevertheless, the optimal price is sufficiently low such that the Lows buy for the first time in period 2. This is an important source of revenue for the firm in period 2 when $\alpha \geq \hat{\alpha}_M$. Interestingly, the Lows entering the market in period 2 realize a positive surplus because they have a higher WTP for the second generation than the Highs who already own a first generation product.

A low PDC firm on the other hand, cannot create significant value from the second generation product due to the high cost it incurs to increase product quality. As a result, the primary focus of a low PDC firm is to maximize its earnings from the endowed quality of the first generation product. It does this by intertemporally discriminating between the Highs and Lows, i.e., it charges a high price and sells to the Highs in period 1 and then reduces price and mops up the demand from the Lows in period 2. We refer to this strategy

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[10]Note that $\frac{d\hat{\alpha}_M}{d\theta} \geq 0$, $\frac{d\hat{\alpha}_M}{d\lambda} \geq 0$, $\frac{d\hat{\alpha}_M}{d\rho} \geq 0$, and $\frac{d\hat{\alpha}_M}{dq_1} \geq 0$. This implies that if any of λ, θ, ρ and q_1 increase, the likelihood of market inversion being optimal increases.
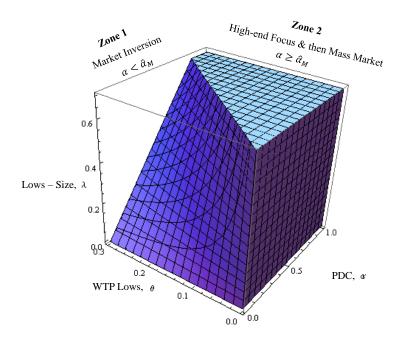
Figure 1: Optimal strategy under complete information when consumers are myopic

as "market inversion"; in period 2, the Highs continue to use the first generation product while the consumers who obtain lower value from the improved version of the product (the Lows) purchase and use the second generation product. Market inversion is optimal for a low PDC firm because the incremental value of the second period product to the Highs is less than its "total value" for the Lows.

In Figure 1, the threshold $\hat{\alpha}_M$ divides the parameter space as a function of the optimal strategy for the supplier. Firms with high PDC spend more on product development in period 2 and develop higher quality products. Further, the higher the quality developed, the opportunity cost to serve the Lows increases (the price reduction needed to sell to the Lows is higher). Conversely, if either θ or α increases, the firm has more incentive to serve the Lows. This explains why in the upper left area of the Figure (Zone 1), the Lows are of high importance (they are the only consumers served in period 2). In contrast, in the upper right zone (Zone 2), the primary sources of revenue are the Highs. However, the Lows enter the market in period 2. They find the second period product attractive at the price which extracts all surplus from the Highs.

To summarize, we find that firms with low PDC tend to market more broadly after the product launch. In contrast, the pricing of firms with high PDC is driven by the WTP of

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Highs.

4.2   Quality is Unobservable

We now consider a situation where the firm cannot convey credible information about product quality before consumers make their first purchase. Similar to the previous section, consumers do not think about second period benefits when making their first period decision. They may, however, infer information about product quality from the firm's actions such as its offer of price. As a result, a firm has the opportunity to 'signal' product quality through its price.[11] The setup we use to investigate the case of unobservable quality is as follows.

Firm Types: We consider two types of firms based on their PDC. A firm with high PDC incurs a lower cost to improve quality, i.e., $\alpha = \alpha_H$ while the low PDC firm incurs a higher cost to improve quality, i.e., $\alpha = \alpha_L$ where $\alpha_H > \alpha_L$.[12] The firm with high PDC has a product in period 1 of quality q_H. The firm with low PDC has a product of lower quality $q_1 = q_L$ in period 1 (i.e., $q_H > q_L$). Further, we assume that $\alpha_H > \hat{\alpha}_M (q_1 = q_H)$ and $\hat{\alpha}_M (q_1 = q_L) > \alpha_L$ which ensures that were quality observable, the optimal strategy of the high PDC firm would be *high-end focus and then mass market* while that of the low PDC firm would be *market inversion*.[13] Note that when either $\alpha_H > \alpha_L > \hat{\alpha}_M (q_1 = q_H)$ or $\hat{\alpha}_M (q_1 = q_H) > \alpha_H > \alpha_L$, both types of firms pursue exactly the same strategy under complete information. In those cases, the high PDC firm is unable to signal its quality. We are interested in parameter conditions where the strategies of the two types of firms, under complete information, are different.

Extensive Form of the Game: Incorporating the asymmetric information about firm type, we have a two stage game under incomplete information which proceeds as follows (see Figure 2):

Stage 1 Nature chooses the firm type, either high (α_H) or low (α_L) quality. As noted earlier, firm type is perfectly correlated with PDC. The firm then chooses p_1 for the first period product. The consumers cannot evaluate quality (nor do they observe the firm type).

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[11]Many researchers have considered various means of signaling quality: advertising (Milgrom and Roberts 1986), price (Choi 1998) and warranties (Soberman 2003). Price as a signal may be distorted either upward (e.g., Choi 1998) or downward (Milgrom and Roberts 1986) to signal higher quality.

[12]This is a reasonable assumption since the quality of the original product is also a result of the efforts of the developers, technical personnel and facilities employed by the firm for the development of the second generation product. We assume that the quality of those resources is highly correlated over time.

[13]Note that since $q_H > q_L$, we have $\alpha_L \leq \frac{2q_L}{1-\rho+\lambda(\theta-\rho)} \left(\frac{\lambda\theta}{1-\rho-\lambda(\theta-\rho)} + \beta \right) < \frac{2q_H}{1-\rho+\lambda(\theta-\rho)} \left(\frac{\lambda\theta}{1-\rho-\lambda(\theta-\rho)} + \beta \right) \leq \alpha_H$.
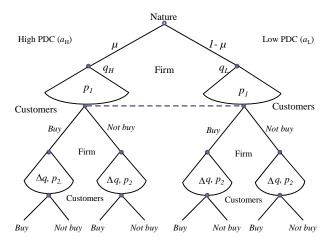
Figure 2: Game tree under asymmetric information

As a result, consumers need to form beliefs about the quality of the product (and the firm's PDC) based on the offer made by the firm. We represent these beliefs with μ, the probability consumers believe that the firm has high PDC. After buying and using the product in period 1, consumers learn about its quality. As a result, consumers know the firm's type at the start of period 2.

Stage 2 At the beginning of period 2 ($t = 2$), the firm invests in product development to deliver additional quality Δq. Because firm type is known at the beginning of period 2, consumers know the quality of the product prior to purchase in period 2. The firm offers a price p_2 for the second period (next generation) product and the consumers decide whether or not to buy it.

The rest of the assumptions are identical to those made for the case of complete information discussed in Section 4.1.

The objective is to identify a 'separating' equilibrium in which the firm maximizes its profit and the consumers receive the quality they believe they are buying (a situation in which a consumer believes she is purchasing a high quality product but actually receives low quality is not an equilibrium). Said differently, the actions of a firm with high PDC that sells a high quality product are constrained by consumers' inferences about quality.

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We introduce this constraint in the high PDC firm's optimization problem. This leads to a standard signaling game in which the uninformed player (the consumer) makes an inference about the type of the informed player (the firm) based on the latter's action.

A key assumption in the analysis is that consumers know that the firm can have two levels of PDC and the absolute levels associated with each type are common knowledge, i.e., consumers know the firm's cost function for increasing quality and they also know that the $\alpha = \alpha_H$ or α_L. To signal higher quality, the high PDC firm changes its first period offer as explained in Proposition 2.

Proposition 2 *When product quality is unobservable, the high PDC firm signals its type by offering a lower price ($p_1^H = q_L$) to myopic consumers in period 1 compared to the case of complete information. The actions of a firm with low PDC are unaffected.*

Proposition 2 shows that a firm with high PDC charges a lower price compared to the price when product quality is observable. In fact, Proposition 2 implies that this price is the same as the complete information price of a firm with low PDC which results in a "tie". However, the high PDC firm can drop the price by an arbitrarily small amount $\varepsilon > 0$ (i.e., $p_1^H = q_L - \varepsilon$) at which the low PDC firm is strictly worse off thereby breaking the tie. The low PDC firm does not mimic this strategy because it is unprofitable. Thus, its actions identify it as a firm with low PDC because it charges the price (and employs the strategy) used under complete information.

Signaling allows a high PDC firm to identify itself in period 1. In period 2, it charges the complete information price because its type is known. This implies that a high PDC firm will charge lower prices for new (first generation) products when quality is unobservable. The impact of a high PDC firm charging lower prices is summarized in Proposition 3.

Proposition 3 *When quality is unobservable and the quality in period 1 is above a threshold ($q_H \geq q_L/\theta$), the high PDC firm covers the market early to signal its type and restricts sales of the new generation product to the Highs in period 2 ("**Market penetration**" strategy). Note that when quality is observable, a firm with high PDC does not employ first period "Market penetration".*

Under complete information, a firm with high PDC focuses on the Highs in period 1 and in period 2, it sells the product broadly (to Highs and Lows). Conversely, when consumers

cannot observe quality, the strategy of the high PDC firm changes. Proposition 3 implies that the high PDC firm signals its type by offering a lower price in period 1 and this makes the first generation product attractive to the Lows as well as the Highs. Then in period 2, the high PDC firm restricts sales to the Highs.[14] In summary, asymmetric information (and the corresponding need to signal) causes a firm with high PDC to completely reverse the launch strategy it would use were quality observable (broad then narrow versus narrow then broad).

It is also useful to underline why a firm with low PDC does not mimic the pricing of the firm with high PDC. To be specific, there is nothing to stop a low PDC firm from copying the high PDC firm's price: this would lead to much first period demand as the firm would sell to the Lows as well as the Highs. However, the main objective of a low PDC firm is to maximize earnings from the *endowed quality* of the first generation product (high product development costs make it infeasible to offer a significant quality improvement in period 2). Were the low PDC firm to mimic the offer of the high PDC firm, it would lose the ability to intertemporally discriminate between the Lows and Highs. Moreover, a small improvement in product quality is naturally offered with a very low price to consumers who already have a product (all consumers have a first generation product with the high PDC strategy described in Proposition 3).

The model highlights who gains and loses when the quality of products is unobservable. The primary loser is the firm with high PDC. In a nutshell, signaling costs money and firms with high PDC (and hence higher quality first period products) need to signal. The primary beneficiaries of asymmetric information are the Highs. When product quality is high, the Highs are able to buy products with an attractive price that is essentially discounted by the seller.

5   Consumers are Forward Looking

In this section we evaluate firm decisions in the same market but where the consumers are "forward looking", i.e., the consumers maximize their utility across the two periods based on rational expectations about the firm's price and quality decisions in period 2. As in the case of myopic consumers, we first consider the case where quality is observable.

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[14]When $\alpha_H < \hat{\alpha}_M$, the firm has low PDC and the optimal strategy is market inversion.

5.1 Quality is Observable

A forward looking consumer with rational expectations buys the product in period 1 if and only if she expects a higher net surplus compared to waiting and purchasing in period 2. For the Lows and Highs respectively, this implies $\theta q_1 - p_1 + \delta\theta q_1 \geq \delta(\theta q_2 - p_2)$ and $q_1 - p_1 + \delta q_1 \geq \delta(q_2 - p_2)$. We now write the utility for the Lows and Highs in terms of the product improvement Δq made to the second generation product:

$$
\begin{aligned}
u_1(\theta_i = \theta) &= \max\{\theta q_1 - p_1 + \delta\theta q_1, \delta(\theta(q_1 + \Delta q) - p_2)\} \text{ for Lows,} \\
u_1(\theta_i = 1) &= \max\{q_1 - p_1 + \delta q_1, \delta(q_1 + \Delta q - p_2)\} \text{ for Highs.}
\end{aligned}
\tag{13}
$$

Using the conventions of Section 4.1, we write the corresponding indicator functions in case of forward looking Lows (Highs) as

$$
I_\theta = \begin{cases} 1 \text{ if } \theta q_1 - p_1 \geq \delta(\theta\Delta q - p_2) \\ 0 \text{ otherwise} \end{cases} \quad \text{and } I_1 = \begin{cases} 1 \text{ if } q_1 - p_1 \geq \delta(\Delta q - p_2) \\ 0 \text{ otherwise} \end{cases}.
\tag{14}
$$

The second period utility from purchase is the same as for myopic consumers given by equation 8. Aside from the value consumers obtain by using the first period product, the model is very similar to the specification of Section 4.

The market demand and firm profit functions are identical to those of Section 4.1.

Extensive Form of the Game: The timing of the game is identical to that of Section 4.1. Only the basis for consumer decisions changes when consumers think ahead.

While the firm strategies remain the same as in Section 4.1 and equation 6, the necessary conditions (or pricing constraints) for each strategy are different and this reflects the forward looking decision basis that consumers use to make decisions.[15]

a) *Market penetration*: $(I_\theta = 1, I_1 = 1)$, and $(J_\theta = 0, J_1 = 1)$. The necessary conditions are $\theta q_1 - p_1 \geq \delta(\theta\Delta q - p_2) \Leftrightarrow p_1 \leq \theta q_1 - \delta(\theta\Delta q - p_2)$ and $\theta\Delta q < p_2 \leq \Delta q$. The firm decision problem, therefore, is

$$
\pi_{MP} = \max_{p_1, p_2, \Delta q} \pi \text{ s.t. } \theta q_1 - \delta(\theta\Delta q - p_2) - p_1 \geq 0, \text{ and } \Delta q - p_2 \geq 0.
\tag{15}
$$

---

[15]See Figure 4 in the Appendix.

b) *High-end focus and then mass market:* $(I_\theta = 0, I_1 = 1)$, and $(J_\theta = 1, J_1 = 1)$. Here, the conditions are $\theta q_1 - \delta(\theta \Delta q - p_2) < p_1 \le q_1 - \delta(\Delta q - p_2)$ and $p_2 \le \Delta q < \theta(q_1 + \Delta q)$. The firm decision problem, therefore, is

$$\pi_{HF} = \max_{p_1, p_2, \Delta q} \pi \text{ s.t. } q_1 - \delta(\Delta q - p_2) - p_1 \ge 0, \text{ and } \Delta q - p_2 \ge 0. \qquad (16)$$

c) *Market inversion:* $(I_\theta = 0, I_1 = 1)$, and $(J_\theta = 1, J_1 = 0)$. The necessary conditions are $\theta q_1 - \delta(\theta \Delta q - p_2) < p_1 \le q_1 - \delta(\Delta q - p_2)$ and $\Delta q < p_2 \le \theta(q_1 + \Delta q)$. The firm decision problem, therefore, is

$$\pi_{MI} = \max_{p_1, p_2, \Delta q} \pi \text{ s.t. } q_1 - \delta(\Delta q - p_2) - p_1 \ge 0, \text{ and } \theta(q_1 + \Delta q) - p_2 \ge 0. \qquad (17)$$

d) *Mass market:* $(I_\theta = 1, I_1 = 1)$, and $(J_\theta = 1, J_1 = 1)$. Here, the conditions are $p_1 \le \theta q_1 - \delta(\theta \Delta q - p_2)$ and $p_2 \le \theta \Delta q$.[16] The firm decision problem, therefore, is

$$\pi_{MM} = \max_{p_1, p_2, \Delta q} \pi \text{ s.t. } \theta q_1 - \delta(\theta \Delta q - p_2) - p_1 \ge 0, \text{ and } \theta \Delta q - p_2 \ge 0. \qquad (18)$$

As earlier, we solve the firm decision problem for each of the above strategies and compare the outcomes to find the strategy that maximizes profit. Proposition 4 describes the optimal strategies for the firm as a function of α when consumers are forward looking.

Proposition 4 *Forward Looking Consumers: Under complete information, a firm having PDC higher than the threshold $\alpha \ge \hat{\alpha}_F$ (where $\hat{\alpha}_F = 2q_1 \frac{\frac{1}{\delta} \frac{1-\lambda-\theta}{1-\theta-\lambda(1-\rho)} + \beta}{1-\theta+(2-\lambda)(1-\rho)}$) sells to both Highs and Lows in period 1 and only to the Highs in period 2 (**"Market penetration"** strategy). A firm having PDC less than the threshold $(\alpha < \hat{\alpha}_F)$ serves the Highs in both periods and the Lows only in period 2 (**"High-end focus and then mass market"** strategy).*

Proposition 4 shows that forward looking behavior by consumers leads to a lower WTP for the first period product because consumers weigh the benefit of consuming today against the cost of waiting to buy in period 2. The impact of this behavior by consumers hurts the firm: forward looking behavior creates a durable goods monopoly problem (Coase 1972). The Highs know that they would trade up in period 2, implying that the first period product is purchased based only on its consumption in period 1. Because the firm is forced to charge a lower price in period 1 (due to the forward looking behavior of consumers), both types of

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[16] Notice that the first period prices are lower under all strategies in case of forward looking consumers.

consumers buy the first generation product. When this occurs, the optimal strategy for the high PDC firm is to develop a higher quality second generation product targeted to the Highs alone and charge a correspondingly higher price for it.

Conversely, the strategy shifts from *Market inversion* to *High-end focus and then mass market* when a firm has low PDC. As with a high PDC firm (when consumers are forward looking), the price that consumers are willing to pay in period 1 is driven downwards. Independent of the strategy employed by the firm, this hurts firm profits. However, when a firm has low PDC, the incremental increase in product quality in period 2 is small (because of the high cost of product development). Accordingly, a firm with low PDC has an incentive to get as much money as it can from its "endowed" first period quality. It accomplishes this by only selling to the Highs in period 1. In a sense, this allows the low PDC firm to charge higher prices in both periods. In period 2, it proves beneficial for the firm to sell the new generation broadly. The Highs are interested in the improved performance of the new generation product and the WTP of the Lows is driven by the total benefit provided by the product as they did not buy in period 1.

In sum, the most important effect created by forward looking behavior by consumers is that consumers (Highs and Lows) have a lower WTP in period 1. This has two consequences. First, it reduces first period prices and constrains the firm independent of PDC. Second, forward looking behavior by consumers brings the Lows into the market sooner when a firm has high PDC. The high PDC firm wrestles with the choice of charging a price that the Lows find acceptable and extracting surplus from the Highs. By serving the Lows in period 1, the high PDC firm unshackles itself in period 2 and is able to charge the Highs a high maximum price for a "significantly improved" second generation product.

In contrast, the firm with low PDC extracts the maximum price in period 1 (from the Highs) and then serves both Highs and Lows in period 2. Interestingly, when consumers are forward looking, the Highs buy in every period independent of the PDC of the firm. In contrast, when consumers are myopic, the Highs remain with the first generation product when the firm has low PDC.

5.2   Quality is Unobservable

As in Section 4.2, we consider a situation where the firm cannot convey credible information about product quality before consumers make their first purchase. Similar to the previous

section, consumers think about their expected second period benefits while making their period 1 decision. Because consumers will make inferences about product quality when it is not observable, a firm may be able to signal its quality through pricing.

Firm Types: Aside from the following assumption, firm types are identical to those for myopic consumers as described in Section 4.2. We assume that $\alpha_H > \hat{\alpha}_F (q_1 = q_H)$ and $\hat{\alpha}_F (q_1 = q_L) > \alpha_L$ to ensure that the optimal strategies of the high PDC firm and low PDC firms are *market penetration high-end focus and then mass market* respectively, when quality is observable. When either $\alpha_H > \alpha_L > \hat{\alpha}_F (q_1 = q_H)$ or $\hat{\alpha}_F (q_1 = q_H) > \alpha_H > \alpha_L$, both types of firms pursue the same strategy under complete information, and the high PDC firm cannot signal its quality. Similar to Section 4.2, parameter conditions where the strategies of the two types of firms under complete information are different lead to signalling.

Extensive Form of the Game: The timing of the game is identical to that of Section 5.1 except for the following: in Stage 1, Nature chooses the firm type either high (α_H) or low (α_L) quality and consumers form beliefs with probability μ that the firm has high PDC. Similar to Section 4.2, consumers become informed about the firm's type before the second period. Proposition 5 explains the optimal firm strategy when consumers are forward looking but cannot observe product quality.

Proposition 5 *When quality is unobservable and consumers are forward looking, the high PDC firm signals its quality by offering a lower price ($p_1^H = \hat{p}_1^H$) than under complete information, but using the same "**Market penetration**" strategy as under complete information. The actions of a firm with low PDC are unaffected.*

When quality is unobservable, a high PDC firm offers a lower price in period 1 to signal its quality. This finding echoes the equilibrium that obtains when consumers are myopic and quality is unobservable (see Proposition 2). There is an important difference, however. Other than charging a lower price (due to the need to make the signal informative), the launch strategy of the high PDC firm is *unaffected* by the observability of quality.[17] That is, a firm with high PDC utilizes a strategy of market penetration independent of whether quality is observable. This points to an important interaction between the way that consumers think about their purchase decision and the observability of quality. When consumers think myopically about decisions, quality being unobservable changes the optimal strategy of a

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[17]The high PDC firm reduces its price to the point at which the low PDC firm does not have an incentive to pretend to be high PDC when quality is not observable.

firm with high PDC (the high quality firm has $q_H \geq q_L/\theta$) from *High-end focus and then mass market* to *Market penetration*. In contrast, when consumers are forward looking, the strategy of a firm with high PDC is unaffected; only the price is different. Perhaps the most interesting finding with regard to the impact of consumers thinking ahead (for their first purchase decision) is the effect it has on the Lows when firms have high PDC. Forward thinking behavior brings the Lows into the market sooner when a firm has high PDC. The basic force driving this finding is the desire of the high PDC firm to capitalize on selling the second generation product to the Highs. The sooner, the Lows are served (and effectively removed from the market), the greater the flexibility of the high PDC firm to capitalize on the high WTP of the Highs for the next sale.

6 Conclusions

The objective of this paper is to examine how the PDC of a firm that sells upgradable durable goods affects marketing and product development decisions in a market where consumers have heterogeneous valuations for performance. Under complete information, the optimal marketing strategy of a firm having a high PDC revolves around selling (and re-selling) to high WTP consumers. Here, extracting value for new product generations from high WTP consumers is critical. This finding may explain why well-known makers of high end consumer electronics (such as Sony, Apple, and Royal Philips Electronics) and sporting equipment such as Völkl (skis) and Graf (hockey skates) make ongoing investments in product development to develop new generations on a regular basis. The firm's efficiency at developing higher levels of performance makes offering new generations on a regular basis attractive.

In contrast, the optimal strategy of firms with low PDC is to focus on expanding the market after serving high WTP consumers in period 1. Because firms with low PDC improve their products less over time, they expand the market over time in order to optimize profitability. Under certain conditions, the strategy of selling to as many consumers as possible leads to "market inversion": the firm serves high WTP consumers with early versions of the product and low WTP consumers buy improved versions. In this case, high WTP consumers continue to use old technology even when a newer version of the product is available.

Typically a firm sells the high and low quality products, respectively, to high and low WTP consumers (see, for example, Maskin & Riley 1984). A phenomenon similar to market inversion known as "vintage effects" has been noted in the literature (see for example,

Bohlmann, Golder and Mitra 2002). When two competing firms enter a market sequentially, the follower uses more recent technology than an incumbent who has committed to older technology. Thus an established market leader is sometimes observed to use less efficient technology (an earlier vintage) than a new entrant. Of course, consistent with our findings, this situation occurs when the new generation product offers a small advantage over the original technology.

In some cases, it is difficult for consumers to evaluate the quality of a new product. For example, many buyers of consumer electronics or specialized sporting equipment appreciate their performance only after having used the product. This is the case when an unknown firm or a firm "without a track record" launches a product that provides unique value. In these situations, a firm with high PDC will signal its higher performance by offering its products at a *lower price* than the optimal price charged by a firm with low PDC. This leads to mass sell-in for the new product in period 1. In the second period, the firm restricts sales of the new generation product to high WTP consumers. In a nutshell, this is a reversal of the strategy used by a firm with high PDC under complete information.

It is important to note that the offering of a firm with low PDC is not affected by the unobservability of product quality. Why does a low PDC firm not mimic the strategy of the high PDC firm and pretend to be higher quality? The reason is that a firm with low PDC optimizes its profit by intertemporally discriminating between high and low WTP. Said differently, the low PDC firm needs to focus on maximizing earnings from the *endowed quality* of the first generation product because the second generation product is only marginally better than the first generation. If the low PDC firm mimics the high PDC firm, it loses the ability to intertemporally discriminate between low and high WTP consumers. This obtains because its type is common knowledge by the time consumers decide whether to buy in the second period.

We also examine how forward looking behavior on the part of consumers affects the launch strategy of firms as a function of the firm's PDC. We show that forward looking behavior causes a firm with high PDC to implement a marketing strategy that better aligns the consumer valuations of product quality and the relative quality of products they consume. In other words, rational expectations of consumers about future products causes a high PDC firm to sell earlier versions of products more broadly (across consumer types) and improved versions only to high WTP consumers. In period 2, low WTP consumers do not trade

up while the high WTP consumers trade up to the second generation product. Finally, we examine how the strategy of a high PDC firm is affected by "hidden quality" when consumers think ahead. Interestingly, "hidden quality" does not qualitatively alter the high PDC firm's marketing strategy; its only effect is to reduce the price of high quality products in period 1 as a high PDC firm "signals" its quality to the market.

Our research shows that product development capability has a significant impact on the marketing strategy a firm should adopt to launch a product in a market where there is significant heterogeneity with regard to consumers' valuation of product performance. In general, firms develop their marketing strategies after products have been developed. After all, why spend time developing a marketing strategy for a product that is not ready?

Our analysis shows that this approach to product development and marketing is not optimal. In particular, the optimal price of the first generation product is affected significantly by a) the PDC of the firm, b) whether consumers assess future benefits when making current decisions, and c) the ease with which consumers can evaluate the quality of a new product. Moreover, the optimal level of investment in product improvement is impacted by the optimal pricing and expected demand for the improved product. When a firm develops sequential generations of a durable product for a heterogeneous market, our study underlines the benefits of utilizing an integrated approach for these two activities. The following table summarizes the optimal strategies of the firm under different conditions analyzed in our model.

Table 2: Summary of Optimal Strategies as a Function of PDC

Consumers →	Myopic		Forward-looking	
Quality → Firm ↓	Observable	Hidden	Observable	Hidden
High PDC	High-end focus & then mass market	Market penetration	Market penetration	Market penetration
Low PDC	Market inversion	Market inversion	High-end focus & then mass market	High-end focus & then mass market

Our study also suggests new areas of future research. One of them is to analyze how competition between firms might affect the results. The model we have presented concerns a monopolistic seller that sells to two segments over time that are different in terms of willingness to pay. Using this structure as a starting point, competition might enter the

problem in two ways. First, competition might result in a reduction of the premium consumers are willing to pay for a firm's product. This would reduce firm incentives to invest in product development. Second, firms might choose to focus on the high or low WTP consumers as a function of their product development capability. Another interesting avenue to explore would be the reactions of an incumbent that has the option of selling in both periods but is faced with a second period entrant whose quality might be high or low.

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Appendix

Derivation of Condition 1

Consider the firm decision in period 1. If the firm sells only to the Highs ($I_\theta = 0, I_1 = 1$), the firm chooses a price $p_1 = q_1$ and obtains a demand of $D_1 = 1 - \lambda$. On the other hand, if it sells to both types of consumers ($I_\theta = I_1 = 1$), it chooses a price $p_1 = \theta q_1$ and obtains a demand of $D_1 = 1$. We can see that the firm earns less profit from selling only to the Highs unless $(1 - \lambda)(q_1 - c) \geq \theta q_1 - c$ where c is the marginal cost. This condition is trivially satisfied as long as $1 - \lambda \geq \theta$.

Derivation of Condition 2

Due to condition 1, the firm serves only the Highs in period 1 ($I_\theta = 0, I_1 = 1$). Consider now the firm decision in period 2. If $\Delta q \geq \theta(q_1 + \Delta q)$ in violation of condition 2, the firm can possibly earn higher profits by charging a higher price equal to Δq at which only the Highs buy ($J_\theta = 0, J_1 = 1$), leading to a demand $D_2 = 1 - \lambda$ because $1 - \lambda \geq \theta$ (condition 1). The Lows are therefore not served.

On the other hand, when $\Delta q < \theta(q_1 + \Delta q)$, if the firm charges a higher price equal to $\theta(q_1 + \Delta q)$, only the Lows buy ($J_\theta = 1, J_1 = 0$), leading to a demand $D_2 = \lambda$. Alternatively, it can charge a lower price equal to Δq at which both types of consumers buy ($J_\theta = 1, J_1 = 1$), leading to a higher demand $D_2 = 1$. Therefore, if the firm has any demand at all in period 2, it is guaranteed that the Lows buy when $\Delta q < \theta(q_1 + \Delta q)$. In other words, if $D_2 > 0$, $J_\theta = 1$ is assured under the sufficient (but not necessary) conditions 2 and 1.

Proof of Proposition 1

We solve the firm's constrained optimization problem for each of the decision alternatives and then compare the profit values across all the strategic alternatives. Figure 3 illustrates a characterization of the market outcomes as a function of the prices of the two periods. We apply the Kuhn-Tucker necessary and sufficient conditions for global maximum for each of the four strategies below as the objective function is concave and the constraints are linear.

Market penetration Substituting $\{I_\theta = I_1 = 1\} \Rightarrow D_1 = 1$, and $\{J_1 = 1, \ J_\theta = 0\} \Rightarrow D_2 = 1 - \lambda$, in equations 6 and 9, we get the Lagrangian

$$\mathcal{L} = p_1 + \delta(p_2 - \rho\Delta q)(1 - \lambda) - \delta\frac{\Delta q^2 + 2\beta q_1 \Delta q}{2\alpha} - \mu_1(p_1 - \theta q_1) - \mu_2(p_2 - \Delta q)$$

where $\mu_1 \geq 0, \ \mu_2 \geq 0$.

The Kuhn-Tucker conditions are

Marginal Condition	Complementary Slackness
$\frac{\partial \mathcal{L}}{\partial p_1} = 1 - \mu_1 \leq 0$	$\frac{\partial \mathcal{L}}{\partial p_1} p_1 = 0$
$\frac{\partial \mathcal{L}}{\partial p_2} = \delta(1 - \lambda) - \mu_2 \leq 0$	$\frac{\partial \mathcal{L}}{\partial p_2} p_2 = 0$
$\frac{\partial \mathcal{L}}{\partial \Delta q} = -\delta\rho(1 - \lambda) - \delta\frac{\Delta q + \beta q_1}{\alpha} + \mu_2 \leq 0$	$\frac{\partial \mathcal{L}}{\partial \Delta q}\Delta q = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_1} = \theta q_1 - p_1 \geq 0$	$\frac{\partial \mathcal{L}}{\partial \mu_1}\mu_1 = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_2} = \Delta q - p_2 \geq 0$	$\frac{\partial \mathcal{L}}{\partial \mu_2}\mu_2 = 0.$

Solving the marginal conditions, we get $\mu_1 = 1, \mu_2 = \delta(1 - \lambda), \Delta q^* = \alpha(1 - \rho)(1 - \lambda) - \beta q_1$, $p_1^* = \theta q_1$, and $p_2^* = \alpha(1 - \lambda)(1 - \rho) - \beta q_1$. The resulting firm profits are:

$$\pi_{MP}^* = \theta q_1 + \frac{\delta[\alpha(1 - \lambda)(1 - \rho) - \beta q_1]^2}{2\alpha}. \tag{A.1}$$

Second Period Price

p_2

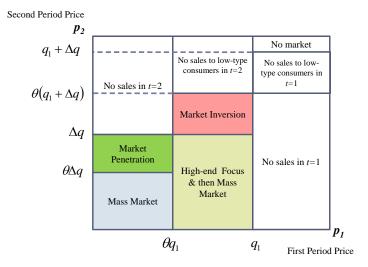$q_1 + \Delta q$

No market

No sales to low-type consumers in $t=2$

No sales to low-type consumers in $t=1$

$\theta(q_1 + \Delta q)$

No sales in $t=2$

Market Inversion

Δq

Market Penetration

$\theta \Delta q$

High-end Focus & then Mass Market

No sales in $t=1$

Mass Market

θq_1 q_1

p_1

First Period Price

Figure 3: Characterization of market outcomes as a function of prices when consumers are myopic

High-end focus and then mass market Substituting $\{I_\theta = 0, I_1 = 1\} \Rightarrow D_1 = 1 - \lambda$, $\{J_1 = 1, J_\theta = 1\} \Rightarrow D_2 = 1$, in equations 6 and 10, we get the Lagrangian

$$\mathcal{L} = p_1(1-\lambda) + \delta(p_2 - \rho \Delta q) - \delta \frac{\Delta q^2 + 2\beta q_1 \Delta q}{2\alpha} - \mu_1(p_1 - q_1) - \mu_2(p_2 - \Delta q)$$

where $\mu_1 \geq 0$, $\mu_2 \geq 0$.

The Kuhn-Tucker conditions are

Marginal Condition

$\frac{\partial \mathcal{L}}{\partial p_1} = 1 - \lambda - \mu_1 \leq 0$

$\frac{\partial \mathcal{L}}{\partial p_2} = \delta - \mu_2 \leq 0$

$\frac{\partial \mathcal{L}}{\partial \Delta q} = -\delta \rho - \delta \frac{\Delta q + \beta q_1}{\alpha} + \mu_2 \leq 0$

$\frac{\partial \mathcal{L}}{\partial \mu_1} = q_1 - p_1 \geq 0$

$\frac{\partial \mathcal{L}}{\partial \mu_2} = \Delta q - p_2 \geq 0$

Complementary Slackness

$\frac{\partial \mathcal{L}}{\partial p_1} p_1 = 0$

$\frac{\partial \mathcal{L}}{\partial p_2} p_2 = 0$

$\frac{\partial \mathcal{L}}{\partial \Delta q} \Delta q = 0$

$\frac{\partial \mathcal{L}}{\partial \mu_1} \mu_1 = 0$

$\frac{\partial \mathcal{L}}{\partial \mu_2} \mu_2 = 0$.

Solving the marginal conditions, we get $\mu_1 = 1 - \lambda$, $\mu_2 = \delta$, $\Delta q^* = \alpha(1-\rho) - \beta q_1$, $p_1^* = q_1$, and $p_2^* = \alpha(1-\rho) - \beta q_1$. The resulting profits are:

$$\pi_{HF}^* = (1-\lambda) q_1 + \delta \frac{[\alpha(1-\rho) - \beta q_1]^2}{2\alpha}. \tag{A.2}$$

Market inversion Substituting $\{I_\theta = 0, I_1 = 1\} \Rightarrow D_1 = 1 - \lambda$, $\{J_1 = 0, J_\theta = 1\} \Rightarrow D_2 = \lambda$, in equations 6 and 11, we get the Lagrangian

$$\mathcal{L} = p_1(1-\lambda) + \delta(p_2 - \rho \Delta q)\lambda - \delta \frac{\Delta q^2 + 2\beta q_1 \Delta q}{2\alpha} - \mu_1(p_1 - q_1) - \mu_2[p_2 - \theta(q_1 + \Delta q)]$$

where $\mu_1 \geq 0$, $\mu_2 \geq 0$.

The Kuhn-Tucker conditions are

Marginal Condition	Complementary Slackness
$\frac{\partial \mathcal{L}}{\partial p_1} = 1 - \lambda - \mu_1 \leq 0$	$\frac{\partial \mathcal{L}}{\partial p_1} p_1 = 0$
$\frac{\partial \mathcal{L}}{\partial p_2} = \delta\lambda - \mu_2 \leq 0$	$\frac{\partial \mathcal{L}}{\partial p_2} p_2 = 0$
$\frac{\partial \mathcal{L}}{\partial \Delta q} = -\delta\lambda\rho - \delta\frac{\Delta q + \beta q_1}{\alpha} + \theta\mu_2 \leq 0$	$\frac{\partial \mathcal{L}}{\partial \Delta q} \Delta q = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_1} = q_1 - p_1 \geq 0$	$\frac{\partial \mathcal{L}}{\partial \mu_1} \mu_1 = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_2} = \theta\left(q_1 + \Delta q\right) - p_2 \geq 0$	$\frac{\partial \mathcal{L}}{\partial \mu_2} \mu_2 = 0.$

Solving the marginal conditions, we get $\mu_1 = 1 - \lambda$, $\mu_2 = \delta\lambda$, $\Delta q^* = \alpha\lambda\left(\theta - \rho\right) - \beta q_1$, $p_1^* = q_1$, and $p_2^* = \theta\left(q_1 + \alpha\lambda\left(\theta - \rho\right) - \beta q_1\right)$. The resulting profits are:

$$\pi_{MI}^* = \left(1 - \lambda\left(1 - \delta\theta\right)\right) q_1 + \delta\frac{\left[\alpha\lambda\left(\theta - \rho\right) - \beta q_1\right]^2}{2\alpha}. \tag{A.3}$$

Mass market Substituting $\{I_\theta = I_1 = 1\} \Rightarrow D_1 = 1$, $\{J_1 = 1 = J_\theta\} \Rightarrow D_2 = 1$ in equations 6 and 12, we get the Lagrangian

$$\mathcal{L} = p_1 + \delta\left(p_2 - \rho\Delta q\right) - \delta\frac{\Delta q^2 + 2\beta q_1\Delta q}{2\alpha} - \mu_1\left(p_1 - \theta q_1\right) - \mu_2\left[p_2 - \theta\Delta q\right]$$
$$\text{where } \mu_1 \geq 0, \ \mu_2 \geq 0.$$

The Kuhn-Tucker conditions are

Marginal Condition	Complementary Slackness
$\frac{\partial \mathcal{L}}{\partial p_1} = 1 - \theta\mu_1 \leq 0$	$\frac{\partial \mathcal{L}}{\partial p_1} p_1 = 0$
$\frac{\partial \mathcal{L}}{\partial p_2} = \delta - \theta\mu_2 \leq 0$	$\frac{\partial \mathcal{L}}{\partial p_2} p_2 = 0$
$\frac{\partial \mathcal{L}}{\partial \Delta q} = -\delta\rho - \delta\frac{\Delta q + \beta q_1}{\alpha} + \theta\mu_2 \leq 0$	$\frac{\partial \mathcal{L}}{\partial \Delta q} \Delta q = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_1} = \theta q_1 - p_1 \geq 0$	$\frac{\partial \mathcal{L}}{\partial \mu_1} \mu_1 = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_2} = \theta\Delta q - p_2 \geq 0$	$\frac{\partial \mathcal{L}}{\partial \mu_2} \mu_2 = 0.$

Solving the marginal conditions, we get $\mu_1 = 1/\theta$, $\mu_2 = \delta/\theta$, $\Delta q^* = \alpha\left(\theta - \rho\right) - \beta q_1$, $p_1^* = \theta q_1$, and $p_2^* = \theta\left(\alpha\left(\theta - \rho\right) - \beta q_1\right)$. The resulting profits are:

$$\pi_{MM}^* = \theta q_1 + \delta\frac{\left[\alpha\left(\theta - \rho\right) - \beta q_1\right]^2}{2\alpha}. \tag{A.4}$$

We now identify the firm strategy that results in the market outcome yielding maximum profits. As before, comparing profits above we can see that $\pi_{HF}^* > \pi_{MP}^* > \pi_{MM}^*$ due to equation 1. Comparing π_{HF}^* and π_{MI}^* we can see that $\pi_{HF}^* \geq \pi_{MI}^*$ only if $\alpha \geq \hat{\alpha}_M$ where

$$\hat{\alpha}_M = \frac{2q_1}{1 - \rho + \lambda\left(\theta - \rho\right)}\left(\frac{\lambda\theta}{1 - \rho - \lambda\left(\theta - \rho\right)} + \beta\right). \tag{A.5}$$

Therefore, **High-end focus and then mass market** is the optimal strategy of the firm if $\alpha \geq \hat{\alpha}_M$. On the other hand if $\alpha < \hat{\alpha}_M$, **Market inversion** is the optimal strategy. **Q.E.D.**

Proof of Proposition 2

The Equilibrium Concept: To solve the game, we use Perfect Bayesian Equilibrium (PBE) concept. The PBE leads to a unique outcome when:

(P) The strategies of the informed player are optimal given the beliefs of the uninformed players.

(B) The beliefs of uninformed players are based on strategies that are consistent with Bayes' Rule.

The PBE imposes a rule of "logical consistency" on the beliefs of uninformed players (Fudenberg and Tirole 1991); that is, the beliefs of uninformed players (i.e., consumers) are derived using Bayes' Rule from the actions of the informed player (the firm) before the uninformed player makes a decision. We assume that $\mu \in [0,1]$ is consumers' prior belief that the firm has high PDC, having observed the firm action or signal p_1, and $\hat{\mu}(p_1)$ is their posterior belief. The triplet $\{p_1^{H*}, p_1^{L*}, \hat{\mu}\}$ constitutes a Perfect Bayesian Equilibrium (PBE) if and only if it satisfies the following conditions related to sequential rationality (**P**) and Bayesian consistency in beliefs (**B**).

(P) $p_1^{H*} \in \arg\max_{p_1} \pi(p_1, \hat{\mu}(p_1))$

(B) If $p_1^{H*} = p_1^{L*} = p_1^*$ then $\hat{\mu}(p_1^*) = \mu$. (Pooling Equilibrium)

If $p_1^{H*} \neq p_1^{L*}$ then $\hat{\mu}(p_1^{H*}) = 1$ and $\hat{\mu}(p_1^{L*}) = 0$. (Separating Equilibrium)

In this game there are two possible equilibria types. In a pooling equilibrium, consumers cannot update their prior belief by observing only the price since both high and low type firms charge the same price. Conversely, in a separating equilibrium consumers can identify the firm type because the two types of firms charge different prices. PBE only imposes logical consistency on the beliefs of the players over actions on *the equilibrium* path; there are no restrictions on the beliefs of the players over actions off the equilibrium path. In signaling games, freedom in specifying off-equilibrium beliefs can lead to multiple equilibria when the off-equilibrium beliefs of uninformed players attribute positive probability to the informed player (the firm) choosing an equilibrium-dominated strategy. The Intuitive Criterion (IC) of Cho and Kreps (1987) eliminates these equilibria by imposing a restriction on the players' beliefs over actions off the equilibrium path.

Intuitive Perfect Bayesian Equilibrium

A PBE violates the intuitive criterion if there exists an action that yields strictly greater payoffs for a player given that the uninformed players ascribe zero probability to a player's action that is "equilibrium-dominated". An action is "equilibrium-dominated" for a player if that action leads to lower profits than another putative equilibrium. In other words, a firm type choosing an "equilibrium-dominated" action cannot increase its profit over what it earns under equilibrium.

In the context of this model, the beliefs of consumers subject to the IC restrict the high PDC firm to a set of strategies (p_1^H) which is equilibrium dominated for a firm with low PDC: were it to implement a strategy from this set, the low PDC firm would earn less than its "guaranteed" level of profit. The only equilibrium that survives the intuitive criterion is a separating equilibrium with minimal inefficient signaling. In addition, a high PDC firm has a profit-increasing deviation from all possible pooling equilibria when signaling is possible.[1] The guaranteed profit for the low PDC firm, π_L^c, is the profit it earns when consumers can observe quality. The low PDC firm has an incentive to mimic a high PDC firm if it increases profit by offering p_1^H: the offer that would be made by a firm with high PDC, i.e., $\pi_L(p_1^H, \hat{\mu} = 1) > \pi_L^c$. In equilibrium, the intuitive criterion rules out these strategies for the high PDC firm. As noted earlier, the intuitive criterion is the basis for the following constraint in the high PDC firm's optimization:

$$\pi_L(p_1^H, \hat{\mu} = 1) < \pi_L^c. \tag{A.6}$$

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[1]When a signal is either costless or inexpensive, signaling may be impossible.

Note that a high PDC firm should not be able increase profits by pretending to be a firm with low PDC, i.e.,

$$\pi_H \left(p_1^L, \hat{\mu} = 0 \right) < \pi_H^c. \tag{A.7}$$

Because $q_L < q_H$, this restriction is satisfied.

The "guaranteed" profit of the low PDC firm is the profit it earns when it offers the price p_1^* which is the optimal price of the low PDC when quality is observable. The guaranteed profit, π_L^c, is obtained by substituting $\alpha = \alpha_L$ and $q_1 = q_L$ into the firm's profit function and optimizing.

All Putative Pooling Equilibria are Unstable based on the Intuitive Criterion

Recall from Proposition 1 that the optimal strategy for the high (low) PDC firm is *High-end focus and then mass market* (*Market inversion*). When quality is unobservable, if the high PDC firm offers the same price which is also the maximum price it can charge as under complete information ($p_1^* \left(\theta_1 = 1, q_1 = q_H \right) = q_H$), it would violate the "no-mimic condition" (equation A.6). This implies that a firm with low PDC will have an incentive to offer the same price as that of the high PDC firm which would result in a pooling equilibrium. We show below, using the Intuitive Criterion, that a pooling equilibrium does not exist.

Suppose there is a putative pooling equilibrium (p_1^*) in which the consumers accept the first period price given the expected quality $E\left(q_1 \right) = \mu q_H + \left(1 - \mu \right) q_L$ given $p_1^* \leq E\left(q_1 \right)$.

Step 1 First, we can find a deviation combination $\left(p^D = p_1^* + D \right)$ such that

$$\pi_L^D \left(p_1^D, \hat{\mu} = 1 \right) = \pi_L^* \left(p_1^*, \mu \right) \tag{A.8}$$
$$\text{where } \pi_L^D \left(p_1^D, \hat{\mu} = 1 \right) = \pi_{HF}^* \left(p_1^* = p_1^D, q_1 = q_L, \alpha = \alpha_L \right) \text{ and}$$
$$\pi_L^* \left(p_1^*, \mu \right) = \pi_{MI}^* \left(p_1^*, q_1 = q_L, \alpha = \alpha_L \right).$$

From the optimization in the Proof of Proposition 1, we can see that $\pi_{HF}^* \left(p_1^* = p_1^D, q_1 = q_L, \alpha = \alpha_L \right)$ $= \left(1 - \lambda \right) \left(p_1^* + D \right) + \frac{\delta[\alpha_L(1-\rho) - \beta q_L]^2}{2\alpha_L}$ and $\pi_{MI}^* \left(p_1^*, q_1 = q_L, \alpha = \alpha_L \right) = \left(1 - \lambda \right) p_1^* + \frac{\delta[\alpha_L \lambda(\theta - \rho) - \beta q_L]^2}{2\alpha_L}$ where D solves $\pi_{HF}^* \left(p_1^* = p_1^D, q_1 = q_L, \alpha = \alpha_L \right) = \pi_{MI}^* \left(p_1^*, q_1 = q_L, \alpha = \alpha_L \right)$. Now, considering a deviation price p_1^{D-} which is infinitesimally less profitable than p_1^D, i.e., $p_1^{D-} = p_1^* + D - \varepsilon$, we have the low PDC firm's profit $\pi_L^{D-} < \pi_L^*$. Thus at the price $D-$, the low PDC firm earns strictly less profit than the equilibrium profit $\pi_L^* \left(p_1^*, \mu \right)$, implying the price $D-$ is equilibrium dominated for the low PDC firm. According to the Intuitive Criterion, consumers cannot ascribe positive probability to a firm type choosing a strategy that is equilibrium dominated. Therefore, the posterior probability of the consumers $\hat{\mu} \left(D- \right) = 1$.

Step 2 Using this price $\left(p_1^D \right)$, the profit of the high PDC firm is $\pi_H^D = \pi_{HF}^* \left(p_1^* = p_1^D, q_1 = q_H, \alpha = \alpha_H \right)$ $> \pi_L^* \left(p_1^*, \mu \right)$ (because $\alpha_H > \hat{\alpha}_M \left(q_1 = q_H \right) > \hat{\alpha}_M \left(q_1 = q_L \right) > \alpha_L$). Therefore if the high PDC firm offers a price infinitesimally lower, i.e., p_1^{D-}, this price will still yield a positive profit $\pi_H^{D-} > \pi_L \left(p_1^*, \mu \right)$. Thus the price p_1^{D-} is not equilibrium dominated for the high PDC firm. The high PDC firm can increase its profits by offering a deviation price p_1^{D-} and convince the consumers that it has a high PDC and also earn a higher profit. Thus, there can be no intuitive pooling equilibrium. **Q.E.D.**

Separating Equilibrium for Myopic Consumers

We consider a separating equilibrium when quality is unobservable. We first obtain the no-mimic condition from the optimization problem of the low PDC firm when $\alpha_L < \hat{\alpha}_M \left(q_1 = q_L \right)$,

using the separating price p_1^H as given below.[2] Solving the game backwards, its second period pricing decision is

$$\pi_L \left(p_1^H, \hat{\mu} = 1\right) = \max_{p_2, \Delta q} \pi_L \left(p_1^H\right) \text{ s.t. } p_2 \leq \theta \left(q_L + \Delta q\right).$$

The Lagrangian is given by

$$\mathcal{L} = (1 - \lambda) p_1^H + \delta \lambda \left(p_2 - \rho \Delta q\right) - \delta \frac{\Delta q^2 + 2\beta q_L \Delta q}{2\alpha_L} - \mu_1 \left(p_2 - \theta \left(q_L + \Delta q\right)\right) \text{ where } \mu_1 \geq 0.$$

Kuhn-Tucker conditions yield $\mu_1 = \delta\lambda > 0$, $\Delta q = \alpha_L \lambda \left(\theta - \rho\right) - \beta q_L$ and $p_2^* = \theta \left(q_L + \Delta q\right)$ with resulting profits:

$$\pi_L \left(p_1^H, \hat{\mu} = 1\right) = (1 - \lambda) p_1^H + \delta\lambda\theta q_L + \delta \frac{\left(\alpha_L \lambda \left(\theta - \rho\right) - \beta q_L\right)^2}{2\alpha_L}. \tag{A.9}$$

Note that the low PDC firm mimics only if $\pi_L \left(p_1^H, \hat{\mu} = 1\right) > \pi_L^c$, which is possible only if $p_1^H > q_L$ where $p_1^H \in [q_L, q_H]$. The no-mimic constraint is obtained by simplifying the condition $\pi_L \left(p_1^H, \hat{\mu} = 1\right) \leq \pi_L^c$ where π_L^c is obtained from the expression A.3 as given by

$$\pi_L^c = [1 - \lambda \left(1 - \delta\theta\right)] q_L + \delta \frac{\left(\alpha_L \lambda \left(\theta - \rho\right) - \beta q_L\right)^2}{2\alpha_L}. \tag{A.10}$$

The no-mimic constraint therefore is given by

$$p_1^H \leq q_L. \tag{A.11}$$

We solve the separating profit maximization problem of the high PDC $\left(\alpha_H > \hat{\alpha}_M \left(q_1 = q_H\right)\right)$ firm using the "no-mimic condition" (Equation A.11) as a constraint: $p_1^H \leq q_L$. This is given by the optimization problem

$$\pi_H^* \left(p_1^H, \hat{\mu} = 1\right) = \max_{p_1^H, p_2, \Delta q} \pi_{HF} \left(\alpha = \alpha_H, \ q_1 = q_H\right) \text{ s.t. } p_1^H \leq q_L.$$

Simplifying the Lagrangian only for the decisions p_1^H (note that the decisions p_2 and Δq remain unchanged from the complete information case), we have

$$\mathcal{L} = (1 - \lambda) p_1^H + \delta \frac{\left(\alpha_H \left(1 - \rho\right) - \beta q_H\right)^2}{2\alpha_H} - \mu_1 \left(p_1^H - q_L\right)$$
$$\text{where } \mu_1 \geq 0.$$

The Kuhn-Tucker conditions yield: $\mu_1 = 1 - \lambda > 0$ and $p_1^{H*} = q_L$. Note that this may lead to a tie which is broken by the high PDC firm by charging $p_1^{H*} = q_L - \varepsilon$ where $\varepsilon > 0$ is infinitesimally small. The separating profit for the high PDC firm therefore is

$$\pi_H^* \left(p_1^{H*}, \hat{\mu} = 1\right) = (1 - \lambda) q_L + \delta \frac{\left(\alpha_H \left(1 - \rho\right) - \beta q_H\right)^2}{2\alpha_H}. \text{ \textbf{Q.E.D.}}$$

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[2] Note that since $\alpha_L < \hat{\alpha}_M \left(q_1 = q_L\right)$, Market Inversion is the optimal strategy for the firm.
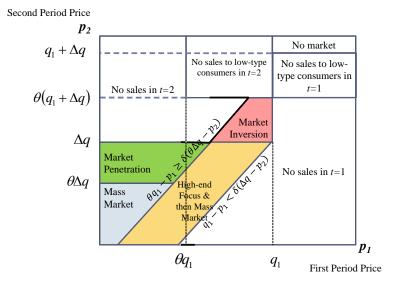
Figure 4: Characterization of market outcomes as a function of prices when consumers are forward looking

Proof of Proposition 3

If the quality of the high PDC firm is above a threshold given by the following condition, the Lows buy in period 1

$$p_1^{H*} \leq \theta q_H \Leftrightarrow q_H \geq q_L/\theta. \tag{A.12}$$

They do not, however, trade up in period 2 since the market penetration strategy is preferable to the mass market strategy, i.e., $\pi_{MP}^* > \pi_{MM}^*$ from Equations A.13 and A.16 under Proof of Proposition 1. **Q.E.D.**

Proof of Proposition 4

The solution approach is exactly the same as that in Proof of Proposition 1. Figure 4 illustrates a characterization of the market outcomes as a function of the prices of the two periods. We apply the Kuhn-Tucker necessary and sufficient conditions for global maximum for each of the four strategies below as the objective function is concave and the constraints are linear.

Market penetration Substituting $\{I_\theta = I_1 = 1\} \Rightarrow D_1 = 1$, and $\{J_1 = 1, \ J_\theta = 0\} \Rightarrow D_2 = 1 - \lambda$, in equations 6 and 15, we get the Lagrangian

$$\mathcal{L} = p_1 + \delta (p_2 - \rho \Delta q)(1 - \lambda) - \delta \frac{\Delta q^2 + 2\beta q_1 \Delta q}{2\alpha} - \mu_1 (p_1 - \theta q_1 + \delta (\theta \Delta q - p_2)) - \mu_2 (p_2 - \Delta q)$$

where $\mu_1 \geq 0, \ \mu_2 \geq 0$.

The Kuhn-Tucker conditions are

Marginal Condition	Complementary Slackness
$\frac{\partial \mathcal{L}}{\partial p_1} = 1 - \mu_1 \le 0$	$\frac{\partial \mathcal{L}}{\partial p_1} p_1 = 0$
$\frac{\partial \mathcal{L}}{\partial p_2} = \delta(1-\lambda) + \delta\mu_1 - \mu_2 \le 0$	$\frac{\partial \mathcal{L}}{\partial p_2} p_2 = 0$
$\frac{\partial \mathcal{L}}{\partial \Delta q} = -\delta\rho(1-\lambda) - \delta\frac{\Delta q + \beta q_1}{\alpha} - \delta\theta\mu_1 + \mu_2 \le 0$	$\frac{\partial \mathcal{L}}{\partial \Delta q} \Delta q = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_1} = \theta q_1 - \delta(\theta\Delta q - p_2) - p_1 \ge 0$	$\frac{\partial \mathcal{L}}{\partial \mu_1} \mu_1 = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_2} = \Delta q - p_2 \ge 0$	$\frac{\partial \mathcal{L}}{\partial \mu_2} \mu_2 = 0.$

Solving the marginal conditions, we get $\mu_1 = 1$, $\mu_2 = \delta(2-\lambda)$, $\Delta q^* = \alpha(1 - \theta + (1-\lambda)(1-\rho)) - \beta q_1$, $p_1^* = \theta q_1 + \delta(1-\theta)(\alpha[1 - \theta + (1-\lambda)(1-\rho)] - \beta q_1)$, and $p_2^* = \alpha[1 - \theta + (1-\lambda)(1-\rho)] - \beta q_1$. The resulting firm profits are:

$$\pi_{MP}^* = \theta q_1 + \frac{\delta[\alpha[1 - \theta + (1-\lambda)(1-\rho)] - \beta q_1]^2}{2\alpha}. \tag{A.13}$$

High-end focus and then mass market Substituting $\{I_\theta = 0, I_1 = 1\} \Rightarrow D_1 = 1 - \lambda$, $\{J_1 = 1, J_\theta = 1\}$ $\Rightarrow D_2 = 1$, in equations 6 and 16, we get the Lagrangian

$$\mathcal{L} = p_1(1-\lambda) + \delta(p_2 - \rho\Delta q) - \delta\frac{\Delta q^2 + 2\beta q_1 \Delta q}{2\alpha} - \mu_1(p_1 - q_1 + \delta(\Delta q - p_2)) - \mu_2(p_2 - \Delta q)$$

where $\mu_1 \ge 0$, $\mu_2 \ge 0$.

The Kuhn-Tucker conditions are

Marginal Condition	Complementary Slackness
$\frac{\partial \mathcal{L}}{\partial p_1} = 1 - \lambda - \mu_1 \le 0$	$\frac{\partial \mathcal{L}}{\partial p_1} p_1 = 0$
$\frac{\partial \mathcal{L}}{\partial p_2} = \delta + \delta\mu_1 - \mu_2 \le 0$	$\frac{\partial \mathcal{L}}{\partial p_2} p_2 = 0$
$\frac{\partial \mathcal{L}}{\partial \Delta q} = -\delta\rho - \delta\frac{\Delta q + \beta q_1}{\alpha} - \delta\mu_1 + \mu_2 \le 0$	$\frac{\partial \mathcal{L}}{\partial \Delta q} \Delta q = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_1} = q_1 - \delta(\Delta q - p_2) - p_1 \ge 0$	$\frac{\partial \mathcal{L}}{\partial \mu_1} \mu_1 = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_2} = \Delta q - p_2 \ge 0$	$\frac{\partial \mathcal{L}}{\partial \mu_2} \mu_2 = 0.$

Solving the marginal conditions, we get $\mu_1 = 1 - \lambda$, $\mu_2 = \delta + \delta(1-\lambda)$, $\Delta q^* = \alpha(1-\rho) - \beta q_1$, $p_1^* = q_1$, and $p_2^* = \alpha(1-\rho) - \beta q_1$. The resulting profits are:

$$\pi_{HF}^* = (1-\lambda)q_1 + \frac{\delta[\alpha(1-\rho) - \beta q_1]^2}{2\alpha}. \tag{A.14}$$

Market inversion Substituting $\{I_\theta = 0, I_1 = 1\} \Rightarrow D_1 = 1 - \lambda$, $\{J_1 = 0, J_\theta = 1\} \Rightarrow D_2 = \lambda$, in equations 6 and 17, we get the Lagrangian

$$\mathcal{L} = p_1(1-\lambda) + \delta(p_2 - \rho\Delta q)\lambda - \delta\frac{\Delta q^2 + 2\beta q_1 \Delta q}{2\alpha} - \mu_1(p_1 - q_1 + \delta(\Delta q - p_2)) - \mu_2[p_2 - \theta(q_1 + \Delta q)]$$

where $\mu_1 \ge 0$, $\mu_2 \ge 0$.

The Kuhn-Tucker conditions are

Marginal Condition	Complementary Slackness
$\frac{\partial \mathcal{L}}{\partial p_1} = 1 - \lambda - \mu_1 \le 0$	$\frac{\partial \mathcal{L}}{\partial p_1} p_1 = 0$
$\frac{\partial \mathcal{L}}{\partial p_2} = \delta\lambda + \delta\mu_1 - \mu_2 \le 0$	$\frac{\partial \mathcal{L}}{\partial p_2} p_2 = 0$
$\frac{\partial \mathcal{L}}{\partial \Delta q} = -\delta\rho\lambda - \delta\frac{\Delta q + \beta q_1}{\alpha} - \delta\mu_1 + \theta\mu_2 \le 0$	$\frac{\partial \mathcal{L}}{\partial \Delta q} \Delta q = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_1} = q_1 - \delta(\Delta q - p_2) - p_1 \ge 0$	$\frac{\partial \mathcal{L}}{\partial \mu_1} \mu_1 = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_2} = \theta(q_1 + \Delta q) - p_2 \ge 0$	$\frac{\partial \mathcal{L}}{\partial \mu_2} \mu_2 = 0.$

Solving the marginal conditions, we get $\mu_1 = 1 - \lambda$, $\mu_2 = \delta$. Note, here, that from the marginal condition $\frac{\partial \mathcal{L}}{\partial \Delta q} \leq 0$, $\Delta q = \alpha (\theta - \lambda \rho - (1 - \lambda)) - \beta q_1 < 0$ under condition 1. Therefore, from the complementary slackness, we get $\Delta q^* = 0$. From the rest of the marginal conditions, we get $p_1 = (1 + \delta \theta) q_1$, and $p_2 = \theta q_1$. Note, however, that since $\Delta q^* = 0$, the forward looking Highs will anticipate the subsequent drop in price to θq_1 in period 2, and therefore, defer their purchase (Coase 1972) forcing the firm to charge $p_1^* = \theta q_1$ and leading to profits:

$$\pi_{MI}^* = \theta q_1. \tag{A.15}$$

Mass market Substituting $\{I_\theta = I_1 = 1\} \Rightarrow D_1 = 1$, $\{J_1 = 1 = J_\theta\} \Rightarrow D_2 = 1$ in equations 6 and 18, we get the Lagrangian

$$\mathcal{L} = p_1 + \delta (p_2 - \rho \Delta q) - \delta \frac{\Delta q^2 + 2\beta q_1 \Delta q}{2\alpha} - \mu_1 (p_1 - \theta q_1 + \delta (\theta \Delta q - p_2)) - \mu_2 [p_2 - \theta \Delta q]$$

where $\mu_1 \geq 0$, $\mu_2 \geq 0$.

The Kuhn-Tucker conditions are

Marginal Condition Complementary Slackness
$\frac{\partial \mathcal{L}}{\partial p_1} = 1 - \mu_1 \leq 0$ $\frac{\partial \mathcal{L}}{\partial p_1} p_1 = 0$
$\frac{\partial \mathcal{L}}{\partial p_2} = \delta + \delta \mu_1 - \mu_2 \leq 0$ $\frac{\partial \mathcal{L}}{\partial p_2} p_2 = 0$
$\frac{\partial \mathcal{L}}{\partial \Delta q} = -\delta \rho - \delta \frac{\Delta q + \beta q_1}{\alpha} - \delta \theta \mu_1 + \theta \mu_2 \leq 0$ $\frac{\partial \mathcal{L}}{\partial \Delta q} \Delta q = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_1} = \theta q_1 - \delta (\theta \Delta q - p_2) - p_1 \geq 0$ $\frac{\partial \mathcal{L}}{\partial \mu_1} \mu_1 = 0$
$\frac{\partial \mathcal{L}}{\partial \mu_2} = \theta \Delta q - p_2 \geq 0$ $\frac{\partial \mathcal{L}}{\partial \mu_2} \mu_2 = 0$.

Solving the marginal conditions, we get $\mu_1 = 1$, $\mu_2 = 2\delta$, $\Delta q^* = \alpha (\theta - \rho) - \beta q_1$, $p_1^* = \theta q_1$, and $p_2^* = \theta (\alpha (\theta - \rho) - \beta q_1)$. The resulting profits are:

$$\pi_{MM}^* = \theta q_1 + \frac{\delta [\alpha (\theta - \rho) - \beta q_1]^2}{2\alpha}. \tag{A.16}$$

We now identify the firm strategy that results in the market outcome yielding maximum profits. Comparing profits above, we can see that $\pi_{MP}^* > \pi_{MM}^* > \pi_{MI}^*$ and $\pi_{HF}^* > \pi_{MM}^*$ due to equation 1. Comparing π_{HF}^* and π_{MI}^*, we can see that $\pi_{HF}^* \geq \pi_{MI}^*$. Next comparing π_{HF}^* with π_{MP}^*, we can see that $\pi_{MP}^* \geq \pi_{HF}^*$ only if $\alpha \geq \hat{\alpha}_F$, where

$$\hat{\alpha}_F = 2q_1 \frac{\frac{1}{\delta} \frac{1 - \lambda - \theta}{1 - \theta - \lambda (1 - \rho)} + \beta}{1 - \theta + (2 - \lambda)(1 - \rho)}. \tag{A.17}$$

Therefore, **Market penetration** is the optimal strategy of the firm if $\alpha \geq \hat{\alpha}_F$. On the other hand, $\pi_{HF}^* > \pi_{MP}^*$ if $\alpha < \hat{\alpha}_F$, i.e., **High-end focus and then mass market** is the optimal strategy. **Q.E.D.**

Proof of Proposition 5

The Equilibrium Concept: Is the same as stated under Proof of Proposition 2.

All Putative Pooling Equilibria are Unstable based on the Intuitive Criterion

Analogous to the case of myopic consumers (see Proof of Proposition 2), the proof that all putative pooling equilibria are unstable follows the same logic. Recall from Proposition 4 that the optimal strategy for the high (low) PDC firm is *Market penetration* (*High-end focus and*

then mass market). If the high PDC firm offers the same price as under complete information, i.e., $p_1^* (\theta_1 = \theta, q_1 = q_H, \alpha = \alpha_H) = \theta q_H + \delta (1 - \theta) (\alpha [1 - \theta + (1 - \lambda) (1 - \rho)] - \beta q_H)$, it would violate the "no-mimic condition" (equation A.6) since the low PDC firm will have an incentive to offer the same price which would result in a pooling equilibrium. We show below using the Intuitive Criterion that a pooling equilibrium does not exist.

Suppose there is a putative pooling equilibrium (p_1^*) in which the consumers accept the first period price given the expected quality $E (q_1) = \mu q_H + (1 - \mu) q_L$ given $p_1^* \leq E (q_1)$.

Step 1 First, we can find a deviation combination $(p^D = p_1^* + D)$ such that

$$\pi_L^D (p_1^D, \hat{\mu} = 1) = \pi_L^* (p_1^*, \mu) \tag{A.18}$$
$$\text{where } \pi_L^D (p_1^D, \hat{\mu} = 1) = \pi_{MP}^* (p_1^* = p_1^D, q_1 = q_L, \alpha = \alpha_L) \text{ and}$$
$$\pi_L^* (p_1^*, \mu) = \pi_{HF}^* (p_1^*, q_1 = q_L, \alpha = \alpha_L).$$

From the optimization in the Proof of Proposition 4, we can see that $\pi_{MP}^* (p_1^* = p_1^D, q_1 = q_L, \alpha = \alpha_L)$ $= p_1^* + D + \delta \frac{[\alpha_L (1 - \lambda)(1 - \rho) - \beta q_L]^2 - \alpha_L^2 (1 - \theta)^2}{2\alpha_L}$ and $\pi_{HF}^* (p_1^*, q_1 = q_L, \alpha = \alpha_L) = (1 - \lambda) p_1^* + \frac{\delta [\alpha_L (1 - \rho) - \beta q_L]^2}{2\alpha_L}$ where D solves $\pi_{MP}^* (p_1^* = p_1^D, q_1 = q_L, \alpha = \alpha_L) = \pi_{HF}^* (p_1^*, q_1 = q_L, \alpha = \alpha_L)$. Now, considering a deviation price p_1^{D-}, which is infinitesimally less profitable than p_1^D, i.e., $p_1^{D-} = p_1^* + D - \varepsilon$, we have the low PDC firm's profit $\pi_L^{D-} < \pi_L^*$ since $\varepsilon > 0$. Thus at the price $D-$, the low PDC firm earns strictly less profit than the equilibrium profit $\pi_L^* (p_1^*, \mu)$, implying the price $D-$ is equilibrium dominated for the low PDC firm. According to the Intuitive Criterion, consumers cannot ascribe positive probability to a firm type choosing a strategy that is equilibrium dominated. Therefore, the posterior probability of the consumers $\hat{\mu} (D-) = 1$.

Step 2 Using this price (p_1^D), the profit of the high PDC firm is $\pi_H^D = \pi_{MP}^* (p_1^* = p_1^D, q_1 = q_H, \alpha = \alpha_H)$ $> \pi_L^* (p_1^*, \mu)$ (because $\alpha_H > \hat{\alpha}_F (q_1 = q_H) > \hat{\alpha}_F (q_1 = q_L) > \alpha_L$). Therefore if the high PDC firm offers a price infinitesimally lower, i.e., p_1^{D-}, this price will still yield a positive profit $\pi_H^{D-} > \pi_L (p_1^*, \mu)$. Thus the price p_1^{D-} is not equilibrium dominated for the high PDC firm. The high PDC firm can increase its profits by offering a deviation price p_1^{D-} and convince the consumers that it has a high PDC and also earn a higher profit. Thus, there can be no intuitive pooling equilibrium. **Q.E.D.**

Separating Equilibrium for Forward-looking Consumers
To identify the separating equilibrium, we first obtain the no-mimic condition from the optimization problem of the low PDC firm using the separating price p_1^H. Solving the game backwards, period 2 pricing decision is

$$\pi_L (p_1^H, \hat{\mu} = 1) = \max_{p_2, \Delta q} \pi_L (p_1^H) \text{ s.t. } p_2 \leq \Delta q.$$

The Lagrangian is given by

$$\mathcal{L} = p_1^H + \delta (1 - \lambda) (p_2 - \rho \Delta q) - \delta \frac{\Delta q^2 + 2\beta q_L \Delta q}{2\alpha_L} - \mu_1 (p_2 - \Delta q) \text{ where } \mu_1 \geq 0.$$

Kuhn-Tucker conditions yield $\mu_1 = \delta (1 - \lambda) > 0$, $\Delta q = \alpha_L (1 - \lambda) (1 - \rho) - \beta q_L$ and $p_2^* = \Delta q$ with resulting profits:

$$\pi_L (p_1^H, \hat{\mu} = 1) = p_1^H + \frac{\delta [\alpha_L (1 - \lambda) (1 - \rho) - \beta q_L]^2}{2\alpha_L}. \tag{A.19}$$

x

Note that the low PDC firm mimics only if $\pi_L \left(p_1^H, \hat{\mu} = 1 \right) > \pi_L^{c*}$ where

$$\pi_L^{c*} = \pi_{HF}^* \left(\alpha = \alpha_L, \ q_1 = q_L \right) = (1 - \lambda) \, q_L + \frac{\delta \left[\alpha_L \left(1 - \rho \right) - \beta q_L \right]^2}{2\alpha_L}. \qquad \text{(A.20)}$$

This condition simplifies to $p_1^H > \hat{p}_1^H$ where

$$\hat{p}_1^H = (1 - \lambda) \, q_L + \delta \lambda \left(1 - \rho \right) \left[\alpha_L \left(1 - \frac{\lambda}{2} \right) \left(1 - \rho \right) - \beta q_L \right]. \qquad \text{(A.21)}$$

Note from the optimization problem for Market penetration (equation A.13) that $\hat{p}_1^H \leq p_1^*$ (where p_1^* is the complete information price of the high PDC firm) is a necessary condition for mimicking. Otherwise, the high PDC firm can separate using its complete information price p_1^*. The no-mimic constraint therefore is given by $p_1^H \leq \hat{p}_1^H$. Solving the separating profit maximization problem of the high PDC firm involves the "no-mimic condition" (Equation A.21) as a constraint. This is given by the optimization problem

$$\pi_H^* \left(p_1^H, \hat{\mu} = 1 \right) = \max_{p_1^H, p_2, \Delta q} \pi_{MP} \left(\alpha = \alpha_H, q_1 = q_H \right) \ \text{s.t.} \ p_1^H \leq \hat{p}_1^H.$$

Simplifying the Lagrangian only for the decisions p_1^H (note that the decisions p_2 and Δq remain unchanged from the complete information case) and solving the marginal conditions, we get: $\mu_1 = 1 - \lambda > 0$ and $p_1^{H*} = \hat{p}_1^H$. The separating profit for the high PDC firm therefore is

$$\pi_H^* \left(p_1^{H*}, \hat{\mu} = 1 \right) = p_1^{H*} + \frac{\left[\delta \alpha_H \left[1 - \theta + (1 - \lambda) \left(1 - \rho \right) \right] - \beta q_H \right]^2}{2\alpha_H}.$$

Note that both high and Lows buy in period 1 and hence **Market penetration** is the optimal strategy also under signaling. **Q.E.D.**

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