

# New Product Introduction Strategies for Conspicuous Durable Goods

(Authors' names blinded for peer review)

It has long been recognized that the purchasing behavior of consumers depends not only on the product characteristics but also on other considerations such as their intrinsic desire for exclusivity. We study the implications of such consumer behavior on the introduction decisions for durable products, namely the product design (the product durability or the quality improvement over the previous generation) and the price of the product. An extensive body of literature argues for the benefits of planned obsolescence. When we account for exclusivity-seeking behavior, we find that firms benefit from designing products with higher durability in conjunction with a high-price, low-volume introduction strategy. A high price jointly exploits the value inherent in a more durable product and moderates the sales volume to achieve the product exclusivity valued by exclusivity-seeking consumers. Another stream of literature argues for the benefits of technological obsolescence. We find that the presence of exclusivity-seeking consumers reinforces the benefits of technological obsolescence and that firms prefer to introduce substantially improved products. Thus, our results show that in the presence of exclusivity-seeking consumers, firms benefit from practicing more technological obsolescence, but curbing planned obsolescence.

*Key words:* Durable products, Product obsolescence; Exclusivity-seeking consumers; Demand externalities

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## 1. Introduction and Related Literature

Many products are conspicuous in nature: their ownership and use can be publicly observed. Examples include cars, watches, consumer electronics and clothes. For such products, prior research in social psychology has established that consumers may exhibit a desire for exclusivity - the more consumers own a product, the less value they derive from owning it (Lynn 1991, Snyder 1992, Simonson and Nowlis 2000, Tian and Hunter 2001); a “BMW in every driveway” dilutes the value of the car (cf., Bagwell and Bernheim 1996). Thus, such consumers may make purchase decisions based not only on product attributes, but also on the purchase decisions made by other consumers in the market (Leibenstein 1950, Fromkin and Snyder 1980). Borrowing from the seminal work of Leibenstein (1950), we refer to such consumers as *snobs*. In this paper, we investigate the effect of snobbish<sup>1</sup> consumer behavior on a firm’s new product introduction strategy, which includes product design (namely the product durability or the quality improvement over the previous generation) and the price of the product.

<sup>1</sup> We use the terms snobbish and exclusivity-seeking interchangeably.

A well-established strategy in practice is *planned obsolescence*, whereby the product is designed to lose value rapidly so as to induce replacement purchases by consumers. This practice dates back to the early 1900's, when Dupont decided to reduce the durability of early versions of nylon stockings to induce replacement (Slade 2006). Planned obsolescence remains a popular strategy in practice (The Economist 2009). For example, Apple has consciously made the process of replacing the battery of iPods difficult as a planned obsolescence strategy (NYT 2007).

An extensive literature on the introduction of durable goods has provided support for the adoption of planned obsolescence, by designing the product to have low durability or by restricting maintenance (see Waldman 2003 for an extensive review). The rationale is that this allows the firm to induce repeat purchases and avoid cannibalization: Since a product with a higher durability transforms over time to a used product that is a closer substitute for a new product, higher product durability leads to greater demand cannibalization in the future (*substitution effect*). At the same time, rational consumers recognize they will derive higher value in the future from continued use or resale if the product retains its value over time, and they are willing to pay a higher price upfront for a higher durability product (*resale value effect*). The literature concludes that the resale value effect is dominated by the substitution effect; thus, it is optimal to plan obsolescence and benefit from repeat purchases (Bulow 1986, Waldman 1996, Hendel and Lizzeri 1999, Waldman 2003).

Another form of obsolescence, *technological obsolescence*, is also observed in practice, where a firm introduces a substantially improved version of the product to induce replacement purchases by consumers (e.g., in the computer industry, c.f., The Economist 2009). Existing research also provides support for adopting technological obsolescence (Waldman 1993, Fishman et al. 1993, Waldman 1996, Fishman and Rob 2000, Nahm 2004). The rationale is that new and improved products make the existing products owned by consumers technologically inferior, inducing them to replace the old products, increasing the firm's profits.

In this paper, we analyze whether a firm benefits from planned obsolescence or technological obsolescence in the presence of exclusivity-seeking consumer behavior. We show that if consumers are snobbish, the firm benefits from introducing products with high durability and not practicing planned obsolescence. In contrast, we also find that the firm benefits from more technological obsolescence in the presence of snobbish consumers. Thus, while both technological obsolescence and planned obsolescence make old products less attractive to consumers and induce them to purchase new products, the presence of snobbish consumer behavior affects them in an opposite manner: It encourages more technological obsolescence, but curbs planned obsolescence.

Our work adds to a stream of papers that incorporate the effects of snobbish consumer behavior on the aggregate demand faced by firms (Becker 1991, Corneo and Jeanne 1997, Amaldoss and Jain 2005a,b) and that examines operational issues such as restricting the sales quantity in the

presence of snobbish consumers (Tereyağoğlu and Veeraghavan 2009). This stream of literature only focuses on non-durable products and does not consider design decisions. We complement it by analyzing the firm's integrated design and pricing strategy when introducing durable products.

Finally, our work contributes to the recent efforts in the new product design and development literature to recognize that consumers purchase a product based on multiple evaluation criteria/dimensions. Schmidt and Porteus (2000), Chen (2001), Kim and Chhajed (2002) and Krishnan and Zhu (2006) account for multi-dimensional product quality. Weber (2008) and Lacourbe et al. (2009) consider consumers who have heterogeneous valuations for product quality and are horizontally differentiated for product features. While all these papers assume that the utility dimensions that influence the consumers' purchase decisions are exogenously defined, we allow for a multi-dimensional valuation where one of the dimensions— product exclusivity— is an endogenous market effect, i.e., it depends on the choices of other consumers.

## 2. The Model

In this section, we describe our assumptions regarding the firm, product, consumer and market characteristics, and the specification of our discrete-time, dynamic, sequential game over an infinite horizon, where the periods are indexed by  $t \geq 0$ .

**Firm and Product Characteristics.** We consider a profit-maximizing monopolist that designs and sells a durable product in every period. For our base model, we only consider planned obsolescence and assume that there is no technological obsolescence, i.e., the firm does not improve the product over time. We assume that the quality of a new product is fixed and without loss of generality, normalized to one. In §4, we modify our model to allow the firm to practice technological obsolescence by introducing successive generations of improved products. The firm determines the durability of the product through the design process, which involves several actions such as using higher performance components, more durable materials, more reliable interfaces between those components or better production equipment.

To capture the inter-temporal substitution effect while still maintaining tractability, we assume that the product has a maximum useful lifetime of two periods. This assumption has been extensively used in the durable goods literature and does not restrict the generality of our results (Hendel and Lizzeri 1999, Huang et al. 2001, Bhaskaran and Gilbert 2005, 2009, Rao et al. 2009). We model the durability of the product introduced in period  $t$  by  $\delta^t \in [0, 1]$ , which represents the relative willingness to pay for a used product as compared to a new product (Desai and Purohit 1998, 1999, Hendel and Lizzeri 1999, Desai et al. 2004, 2007). Note that  $\delta^t = 0$  represents a product that only lasts for one period; and  $\delta^t > 0$  means that the product lasts for two periods. If  $\delta^t > 0$ , as the product durability increases, used units provide a higher utility and pose a greater cannibalization

threat to the firm's new products. If  $\delta^t = 1$ , the product does not depreciate with use. It is reasonable to assume that a product with higher durability requires a higher per-unit cost of production, denoted by  $c(\delta)$ , where  $c'(\delta) \geq 0$ .<sup>2</sup>

## 2.1 Consumer and Market Characteristics

Consumers derive utility from two different factors: the product quality and the exclusivity of the product. For ease of exposition, we assume that while the consumers exhibit heterogeneity in their base valuations of product quality, they exhibit homogeneity in their sensitivity to product exclusivity. We discuss the implications of heterogeneity in their sensitivity to exclusivity in §3.2.

The first component of the consumer utility is  $\theta$  for a new product and  $\delta\theta$  for a used product, where  $\theta$  is the per-period consumer valuation for product quality. We assume that  $\theta$  is uniformly distributed in  $[0, 1]$ . Thus, we have a vertical differentiation model, where ceteris paribus, every consumer (weakly) prefers a new product over a used product, i.e.,  $\delta\theta \leq \theta$  (Waldman 1996, Desai and Purohit 1998, Hendel and Lizzeri 1999). Without loss of generality, the size of the market is normalized to one. A consumer uses at most one product in a given period.

Following Amaldoss and Jain (2005b), we model the second component of the consumer utility as  $-\lambda Q_e$ , where  $Q_e$  is the expectation of the total volume of products owned by consumers in that period, and  $\lambda \geq 0$  represents consumers' sensitivity to exclusivity (or "snobbishness").  $-\lambda Q_e$  decreases in  $Q_e$  and consequently captures exclusivity-seeking behavior, i.e., a consumer experiences a greater utility loss from the same product as more consumers own it. Our specification makes the implicit assumption that consumers are equally sensitive to the presence of new and used products. If we relax this to allow for a differential sensitivity to new and used products, our results apply with a redefinition of  $\lambda$  as the average sensitivity across new and used products (see discussion in Appendix §A2).

Putting the two components of consumer utility together, the per-period gross utility of consumer type  $\theta$  from using a new product in period  $t$  is given by  $u_n^t(\theta, Q_e^t) = \theta - \lambda Q_e^t$  and that from a used product in period  $t$  is given by  $u_u^t(\theta, Q_e^t) = \delta^{t-1}\theta - \lambda Q_e^t$ .

We assume that consumers are forward-looking (cf., Song and Chintagunta 2003, Nair 2007) and form expectations of price and product durability in the future. Similar to the durable goods literature, we assume that these expectations are perfect (Desai and Purohit 1998, Hendel and Lizzeri 1999, Huang et al. 2001). All information regarding the cost structures and preferences are common knowledge and all players have a common discount factor  $0 < \rho < 1$ . In order to eliminate the uninteresting cases where the business is never profitable for the firm, we assume  $c(\delta) < 1 + \delta$ .<sup>3</sup>

<sup>2</sup> Our qualitative results remain unchanged even when we assume that there is a durability-dependent upfront design cost (see discussion in Appendix §A2).

<sup>3</sup> If a firm designs a product with durability  $\delta$ , the valuation of the highest consumer type ( $\theta = 1$ ) for this product,  $1 + \delta$ , should be higher than the per-unit cost of producing this product,  $c(\delta)$ .

Finally, in order to capture the consumers' expectation of the product exclusivity, we use a rational expectations framework where each consumer has the same expectation about the volume of products owned by consumers ( $Q_e$ ) and this expectation is correct in equilibrium. This is a common assumption not only in the network and consumption externalities literature (Becker 1991, Katz and Shapiro 1994, Amaldoss and Jain 2005a) but also in the durable goods literature (Stokey 1981, Bond and Samuelson 1984). Amaldoss and Jain (2005a) experimentally test the predictions from a consumer-choice based model that uses a rational expectations equilibrium and find that they approach the actual outcomes at the aggregate demand level.

## 2.2 Sequence of Events and Specification of the Game.

In our model, the firm and consumers move sequentially in each period. In our base model, the firm first makes the design decision ( $\delta^t$ ), followed by the price of a new product ( $p_n^t$ ) in every period. Observing these, the consumers make their purchasing decisions. Consumers who already own a product that still has useful life left may choose to either keep their used product or purchase a new one and sell the used one on the secondary market. Since there is typically a large number of individual sellers and buyers in the secondary market, we assume that the secondary market is competitive and there is a market-clearing price  $p_u^t$  for used products (cf., Desai and Purohit 1998, Huang et al. 2001). Note that although the firm does not have direct control of the secondary market, it can indirectly influence it through its new product introduction strategy (i.e., durability and price).

We model the problem as a discrete-time, infinite-horizon game. There are three reasons for this: First, at  $t = 0$ , there are no existing used products, so there is an initial transient time where their supply builds up. Second, using a finite horizon requires specifying artificial terminal conditions, which can skew the results based on the specific terminal condition used (cf., Huang et al. 2001). The time inconsistency effect is also avoided since we consider a product with finite durability in an infinite-horizon setting (Huang et al. 2001). Third, an infinite planning horizon simplifies our analysis and allows us to obtain closed-form results, in contrast to the two-period model commonly used in the durable goods literature. We can show that our qualitative insights are the same under a two-period model (see Appendix §A2).

## 3. Analysis

In this section, we first develop the demand functions by solving the consumer's problem in §3.1. In §3.2, we characterize the rational expectations equilibrium and analyze the firm's optimal pricing and design strategy.

### 3.1 Demand functions

Let consumer  $\theta$ 's period- $t$  action vector be defined as  $a^t(\theta) = (b_n^t(\theta), b_u^t(\theta), i^t(\theta))$ , where  $b_n^t(\theta)$ ,  $b_u^t(\theta)$  and  $i^t(\theta)$  are indicator variables corresponding to buying a new product (BN), buying a used product (BU), and remaining inactive (I), respectively. Let  $p_n^t$  and  $p_u^t$  denote the period- $t$  price of a new product and the market-clearing price for a used product on the secondary market, respectively.

A consumer's utility in period  $t$  depends on their expectation of the total volume of products owned by consumers ( $Q_e^t$ ) in the same period  $t$ . Since the product has positive durability and lasts for two periods, a consumer's payoff in any given period depends on her action in the previous period and the prices in the current period (see Table 1 for the expressions of the period- $t$  net utility  $U_\theta[a^t(\theta); a^{t-1}(\theta), p^t, Q_e^t]$  of a consumer  $\theta$  from action  $a^t(\theta)$ , given previous action  $a^{t-1}(\theta)$ ). Thus, the dynamics are Markovian. As in the previous literature, we restrict our attention to Markov-perfect equilibria, which assume that strategies only depend on the payoff-relevant history that is summarized by the current state (Fudenberg and Tirole 1991). A Markov-perfect equilibrium in the infinite horizon is one in which all time dependence has dropped out. However, cyclic behavior is still possible. Similar to Huang et al. (2001) and Hendel and Lizzeri (2002), we focus on an equilibrium in which all firm decisions are constant in time or a "focal point" (where  $\delta^t = \delta$  and  $p_n^t = p_n$ ). In order to find this equilibrium, we solve the time-independent Bellman equations of the consumer and the firm, subject to the market clearance conditions (see Appendix §A1).

**Table 1** Net utility for consumer  $\theta$  from action  $a^t(\theta)$  in period  $t$ , given a previous-period action  $a^{t-1}(\theta)$ .

$a^{t-1}(\theta)   a^t(\theta)$	New	Used	Inactive
New	$\theta - \lambda Q_e^t - p_n^t + p_u^t$	$\delta^{t-1}\theta - \lambda Q_e^t$	$p_u^t$
Used	$\theta - \lambda Q_e^t - p_n^t$	$\delta^{t-1}\theta - \lambda Q_e^t - p_u^t$	0
Inactive	$\theta - \lambda Q_e^t - p_n^t$	$\delta^{t-1}\theta - \lambda Q_e^t - p_u^t$	0

It is straightforward to show that there are at most four undominated consumer strategies in equilibrium (see Appendix §A1): In decreasing order of the consumer type  $\theta$  that adopts them, always buy new products (BNBN), buy new and use for two periods (BNBU), buy used products from the secondary market in every period (BUBU) and remain inactive (II). The market-clearing price for used goods  $p_u$  is determined by equating supply and demand for used products. Aggregating over all  $\theta$  yields the new product demand  $D_n(p_n, \delta; Q_e)$  and the used product demand  $D_u(p_n, \delta; Q_e)$  at the focal point, which are given by  $D_n(p_n, \delta; Q_e) = D_u(p_n, \delta; Q_e) = \frac{2\rho(1-p_n)+(1+\rho)^2(\delta-\lambda Q_e)}{2(\rho+\delta(1+\rho+\rho^2))}$ .<sup>4</sup> For a rational expectations equilibrium, we require that consumer expectations about the volume of

<sup>4</sup>Note that in equilibrium, the new product demand is equal to the demand for used products on the secondary market. The reason for this is that the only consumers who decide to buy a new product are those who already own the previous generation product and choose to sell it on the secondary market to buy a new one from the firm.

products owned by consumers are correct in equilibrium, and since the volume of products owned by consumers is given by  $D(p_n, \delta; Q_e) = D_n(p_n, \delta; Q_e) + D_u(p_n, \delta; Q_e)$ , we need  $D(p_n, \delta; Q_e) = Q_e$  to hold. Let  $D^*(p_n, \delta)$  and  $D_n^*(p_n, \delta)$  denote the total volume of products owned by consumers and the new-product demand under the rational expectations equilibrium, respectively.

### 3.2 Product Introduction Strategy

At the focal point, the firm's problem reduces to maximizing its per-period profit. To reflect the natural sequence of decision making in this context, we assume that the firm first makes the design decision, followed by the pricing decision. We find the subgame perfect equilibrium by solving the firm's problem using backward induction. Thus, we begin by determining the optimal price for the new product ( $p_n$ ) that maximizes the firm's per-period profit for a given durability, given by  $\max_{p_n} \Pi(p_n, \delta) = (p_n - c(\delta))D_n^*(p_n, \delta)$ , where  $D_n^*(p_n, \delta)$  is derived from the conditions required for the rational expectations equilibrium.

**PROPOSITION 1.** *There exists a unique rational expectations equilibrium for the total volume of products owned by the consumers. The equilibrium price is given by  $p_n^*(\delta) = \frac{\delta(1+\rho^2)+2\rho(1+c(\delta))}{4\rho}$  and the corresponding demand for new products is given by  $D_n^*(\delta) = \frac{\delta(1+\rho^2)+2\rho(1-c(\delta))}{8(\lambda(1+\rho)^2+\rho+\delta(1+\rho+\rho^2))}$ , which strictly decreases in  $\lambda$ .*

To analyze the firm's design strategy, we specify the functional form for the cost of providing durability as  $c(\delta) = c\delta^2$ . This quadratic form has been commonly used in the literature (Mussa and Rosen 1978, Moorthy 1988, Kim and Chhajed 2002, Krishnan and Zhu 2006) and allows to capture a non-linear specification for cost, while still maintaining tractability. In addition, for the rest of our analysis, we assume no discounting, i.e.,  $\rho = 1$ . This simplifies our expressions and helps us to obtain analytical results for the design choice, even with quadratic cost functions.<sup>5</sup> Substituting the optimal value of  $p_n^*(\delta)$ , the firm's design problem is given by  $\max_{0 \leq \delta \leq 1} \Pi(\delta) = \frac{(1+\delta-c(\delta))^2}{4(1+3\delta+4\lambda)}$ .

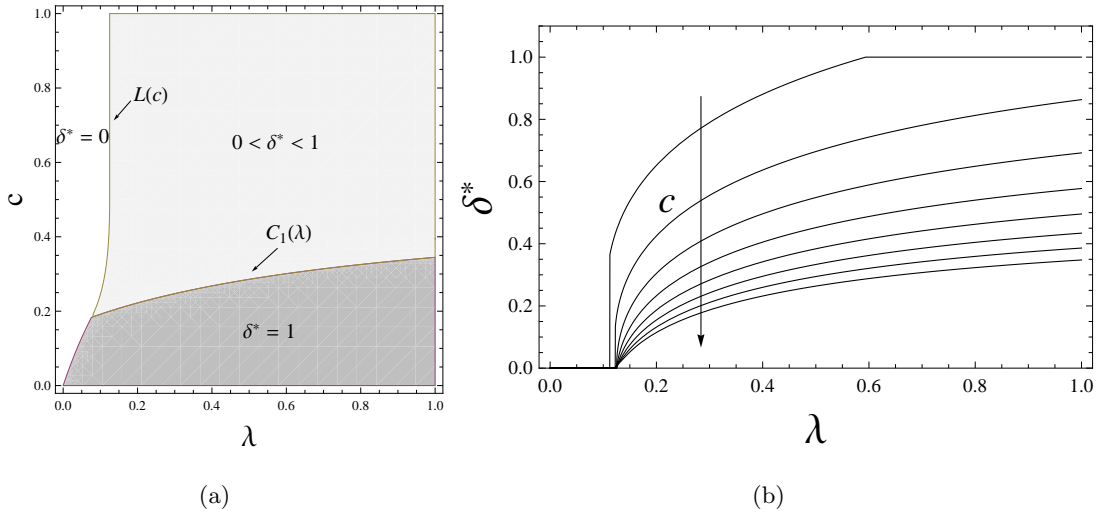
**PROPOSITION 2.** *The firm practices planned obsolescence ( $\delta^* = 0$ ) if and only if  $\lambda \leq L(c)$ , where  $L(0) = 0$ .*

Recall that the case where consumers are not exclusivity-seeking has been extensively studied in the literature and the conclusion is that firms benefit from adopting planned obsolescence ( $\delta^* = 0$ ) (Bulow 1986, Waldman 1996, Hendel and Lizzeri 1999, Waldman 2003). In contrast to this stream of literature, we show that when consumers value product exclusivity, planned obsolescence is often not attractive for the firm (Figure 1a). To understand what drives this result, first consider the case where providing durability is costless, i.e.,  $c = 0$ . In this case, the above proposition shows that as long as consumers exhibit the slightest exclusivity-seeking behavior,  $\lambda > 0 (= L(0))$ , planned

<sup>5</sup> Nevertheless, it can be shown that  $\rho < 1$  provides similar structural results and qualitative insights.

obsolescence is no longer optimal. The reason for this complete reversal is as follows: A lower durability exerts a negative pressure on the price that the firm can charge for the new product (due to its lower resale value). The only way this negative effect can be moderated is through selling a larger volume of products. However, when consumers value exclusivity, this can exert a further negative effect on the price that the firm can charge. The net effect is that in the presence of snobbish consumers, the firm's profitability decreases as the durability is lowered. Thus, under  $c = 0$ , the firm benefits from offering maximum durability, completely rejecting a planned obsolescence strategy.

**Figure 1** Design strategy in the presence of exclusivity-seeking consumers. In panel (a), offering a durable product is optimal in the gray and black regions (defined by  $\lambda > L(c)$ ), with maximum durability  $\delta^* = 1$  in the black region (where  $c < C_1(\lambda)$  holds) and  $0 < \delta^* < 1$  in the gray region. Panel (b) plots the optimal durability as a function of snobbishness  $\lambda$ . The optimal durability increases in  $\lambda$  and decreases in  $c$ .



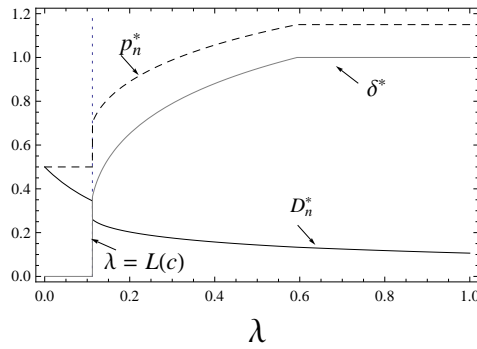
More generally, when it is costly to provide durability ( $c > 0$ ), it is optimal to offer a non-durable product only if the consumers' sensitivity to exclusivity is sufficiently low,  $\lambda \leq L(c)$  (see Figure 1a); the only thing stopping the firm from offering positive durability for all  $\lambda > 0$  is that it is costly to do so (see Figure 1b where  $\delta^*$  decreases in  $c$ ). In this setting, as the consumer snobbishness increases, the negative externality is larger, requiring a much higher product durability to moderate its detrimental effect on the profits, i.e.,  $\delta^*$  increases in  $\lambda$  (see Figure 1b).

**PROPOSITION 3.** *In equilibrium, the durability  $\delta^*$  and the new-product price  $p_n^*$  are non-decreasing in the consumer snobbishness  $\lambda$  and the new-product demand  $D_n^*$  decreases in  $\lambda$ .*

Proposition 3 and Figure 2 illustrate the firm's new product introduction strategy in the presence of snobbish consumers. Recall that as consumers become more snobbish, the negative externality

increases, which has a negative impact on the firm's profits. The firm can compensate consumers for the higher negative externality with two different levers: decrease the price of the new product or offer a more durable product. If consumer snobbishness is low enough ( $\lambda \leq L(c)$ ), the firm prefers to not react to it and does not use either of the two levers.<sup>6</sup>

**Figure 2** New Product Introduction Strategy (durability  $\delta^*$  and new-product price  $p_n^*$ ) and the resulting demand  $D_n^*$  as a function of  $\lambda$  for  $c(\delta) = 0.3\delta^2$ .  $\delta^*$  and  $p_n^*$  are non-decreasing in  $\lambda$  and  $D_n^*$  decreases in  $\lambda$ .



As the consumer snobbishness increases beyond  $L(c)$ , the firm begins to utilize durability as a lever to moderate the negative effect of a higher  $\lambda$ . Increasing the product durability is costly, but consumers are also willing to pay a higher price for the product (due to a higher resale value). This enables the firm to increase the price to exploit this additional value. However, the firm has an additional reason to increase the price: it makes the product more exclusive. If the firm increased its price to only exploit the additional value inherent in a more durable product, one would expect the demand to remain unchanged. However, the new-product demand strictly decreases with increased consumer snobbishness, implying that the firm increases the new product price to also benefit from the value of making the product more exclusive. Thus, offering higher durability and charging a higher price are complementary levers to moderate the negative effect of an increase in the consumer snobbishness.

Finally, once the firm reaches maximum durability (which happens at  $\lambda = 0.593$  in Figure 2), the only feasible lever to compensate consumers for their higher snobbishness is to decrease the price. However, this would also increase the demand for the new product. Thus, the firm prefers to maintain the new product price at a constant level and allow the demand to decrease as  $\lambda$  increases; this behavior is qualitatively the same as where  $\lambda \leq L(c)$ .

*The Role of Heterogeneity in Consumer Sensitivity to Exclusivity.* We assumed that all consumers are equally sensitive to product exclusivity. It is straightforward to relax our model by allowing

<sup>6</sup>Since the firm offers a non-durable product in this region, this result is similar to that one can obtain from the model used in the literature for non-durable products (cf., Amaldoss and Jain 2005a).

for a fraction  $\beta \in [0, 1]$  (independent of  $\theta$ ) of the consumers to have sensitivity to exclusivity  $\lambda_h > 0$  (referred to as the more snobbish consumers), while the rest of the consumers have a lower sensitivity to exclusivity given by  $\lambda_l$  (referred to as the less snobbish consumers), where  $0 < \lambda_l < \lambda_h$ . The firm then has to decide whether it would prefer to set the durability and price such that either both consumer types or only one type buy the product (see Appendix §A2 for more details). It is straightforward to see that the less snobbish consumers will always buy the product, but the more snobbish consumer will not buy the product when they are sufficiently snobbish and constitute only a small fraction of the market.

If only the less snobbish consumers buy the product, the firm's optimal strategy is similar to our homogeneous case, except with  $\lambda = \lambda_l$ . Thus, it prefers planned obsolescence only if the  $\lambda_l$  is sufficiently low. The equilibrium durability and the price are non-decreasing in  $\lambda_l$ . If both types of consumers buy the product, the firm's problem is similar to our homogeneous case, except with  $\lambda = \bar{\lambda} \doteq \beta\lambda_h + (1 - \beta)\lambda_l$ . Thus, the firm prefers to offer a non-durable product only if the weighted average of the snobbishness ( $\bar{\lambda}$ ) in the market is sufficiently low. The equilibrium durability and the new-product price are non-decreasing in  $\lambda_h$ ,  $\lambda_l$  and  $\beta$ . Thus, our main results, i.e., that the optimal durability and price are non-decreasing in the snobbishness of the market, hold even in the presence of heterogeneity in the consumers' snobbishness levels.

#### 4. Technological Obsolescence

Throughout the paper, we focused on whether the firm benefits from making products obsolete through low durability, i.e., planned obsolescence. However the firm may use another form of obsolescence – technological obsolescence, whereby it innovates and introduces improved versions of the product (Waldman 1993, 1996, Fishman and Rob 2000, Nahm 2004). New and improved products make the existing products owned by consumers technologically inferior, inducing them to replace the old products, and increasing the firm's profits.

We now consider the firm's technological obsolescence strategy. In order to focus on this effect, we simplify our model by assuming an exogenous and fixed product durability ( $\delta$ ). Instead, the firm's design decision is the incremental quality improvement over the previous product generation. We denote the quality of new products offered in period  $t$  by  $q^t$ , where without loss of generality, initial quality is normalized to  $q^0 = 1$ . We assume that every improvement made by the firm builds on the previous generation and quality is cumulative: Suppose the firm makes an improvement  $\alpha^t$  in the product generation to be introduced in period  $t$ . The product quality in period  $t$  is then given by  $q^{t-1} + \alpha^t$  (see Fishman and Rob 2000, Plambeck and Wang 2009 for a similar framework). The period- $t$  gross utility of a consumer from using a current-generation (new) product is given by  $u_n^t(\theta, Q_e^t) = (q^{t-1} + \alpha^t)\theta - \lambda Q_e^t$ , and that from a previous-generation (old) product is given by

$u_u^t(\theta, Q_e^t) = \delta q^{t-1} \theta - \lambda Q_e^t$ . It is reasonable to assume that a larger improvement in product quality imposes a higher per-unit cost for the firm, denoted by  $k(\alpha) = k\alpha^2$ . To rule out the uninteresting cases, we assume that  $k(\alpha) + c(\delta) < 1 + \alpha + \delta$ .

The firm's problem in this case is an infinite-horizon dynamic game, where in each period, the firm chooses the incremental improvement in the new product generation denoted by  $\alpha^t$  and the price for a new product  $p_n^t$ , and the consumers decide whether to purchase a product. However, since consumers have heterogeneous willingness to pay for product quality and there is a market-clearing mechanism on the secondary market, there is no known general procedure to analytically solve this problem in closed form.<sup>7</sup> In order to solve the problem, we restrict our attention to myopic, stationary and state-dependent policies for the firm.<sup>8</sup> This is also consistent with practice, where firms typically do not have complete information on future technology improvements and make their decisions based on the near-term horizon (Levinthal and March 1993, Kostoff and Schaller 2001). The next proposition highlights the firm's optimal technological obsolescence strategy in the presence of snobbish consumers.

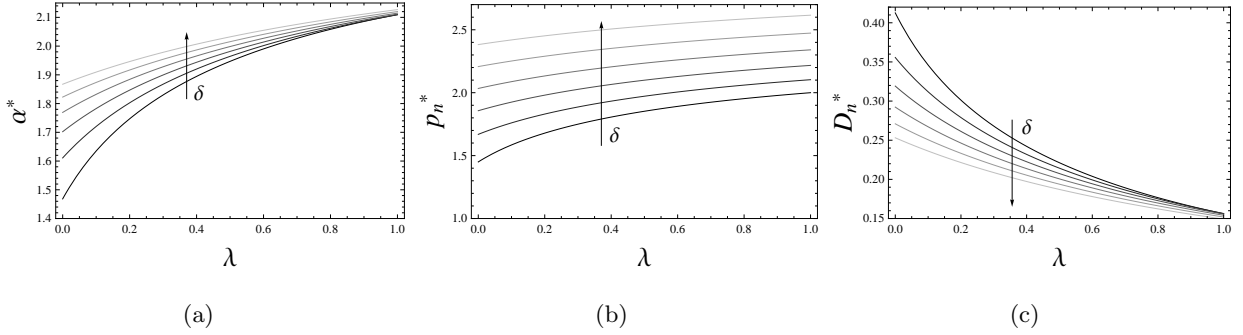
**PROPOSITION 4.** *The firm practices technological obsolescence ( $\alpha^* > 0$ ). The inter-generational quality improvement  $\alpha^*$  and the new-product price  $p_n^*$  increase in  $\lambda$ .*

The above proposition shows that in the presence of exclusivity-seeking consumers, the firm benefits from more technological obsolescence as the snobbishness of consumers increases (see Figure 3a). The reason for this is as follows: As the consumers become more snobbish, the negative externality they incur increases, which has a negative effect on the firm's profit. The firm can moderate this negative effect by either decreasing the price or increasing the product quality. The firm prefers to do latter (see Figure 3a) and in parallel, charges a higher price (see Figure 3b); not only to exploit the higher quality of the product, but also to make the product more exclusive, limiting the negative externality due to the exclusivity-seeking consumer behavior. We can also see from Figures 3a and 3b that the inter-generational improvement and the new-product price increase in the durability of the product. This is because a more durable product makes inducing replacement more difficult, requiring a more improved product, which also allows the firm to charge

<sup>7</sup> In particular, since consumers are heterogeneous and there is trade on the secondary market, in every period, the consumers and the firm's decisions depend not only on the incremental improvement in the product quality, but also on the quality of the previous generation. Thus, the firm's problem is not independent of the state (i.e., the quality of the previous generation) and a myopic policy is not guaranteed to be optimal as in Fishman and Rob (2000) and Plambeck and Wang (2009), where consumers are homogeneous in their valuations. Moreover, in our model, the firm's per-period payoff is not separable in the action ( $\alpha^t$ ) and state ( $q^{t-1}$ ) (which interact in a complex manner). One could simplify our model to only consider homogeneous consumers, which yields a setting where a myopic policy is optimal (as in Fishman and Rob 2000, Plambeck and Wang 2009). However, having heterogeneity in consumers' valuations is required in our model: otherwise current and previous generation products do not coexist in the market.

<sup>8</sup> The consumers' strategy is not constrained to be myopic and they are allowed to play their optimal two-period strategies.

**Figure 3** **New Product Introduction Strategy with Technological Obsolescence (inter-generational improvement  $\alpha^*$  and new-product price  $p_n^*$ ) and the resulting demand  $D_n^*$  as a function of  $\lambda$  for  $c(\delta) = 0.2\delta^2$ ,  $k(\alpha) = 0.2\alpha^2$  and previous-generation quality  $q = 1$ .  $\alpha^*$  and  $p_n^*$  increase in  $\lambda$  and  $D_n^*$  decreases in  $\lambda$ . The rate of increase of  $\alpha^*$  and  $p_n^*$  and the rate of decrease of  $D_n^*$  with respect to  $\lambda$  is smaller for a more durable product.**



a higher price. As can also be seen in Figure 3c, a higher price and a higher inter-generational improvement jointly result in a decrease in the new product demand as durability increases.

Recall that the existing literature states that a firm may prefer to practice planned and/or technological obsolescence, as both of them make old products less attractive to consumers and induce replacement purchases (Waldman 2003). Interestingly, our results show that exclusivity-seeking consumer behavior affects these strategies in a contrasting manner: The firm prefers to practice more technological obsolescence, but curbs planned obsolescence. In fact, technological obsolescence and product durability act as substitutes in the presence of exclusivity-seeking consumers: The increase in the inter-generational improvement due to increased consumer snobbishness is lower for a more durable product, as seen by flatter curves for higher durability in Figure 3a. The reason for this is as follows: Practicing a higher degree of technological obsolescence allows the firm to charge a higher price for the improved product and also utilize this to make the product more exclusive. In contrast, planned obsolescence naturally requires the firm to decrease its price, which makes the product less exclusive and is detrimental to the firm's profit. Thus, these two forms of obsolescence are not interchangeable in the presence of exclusivity-seeking consumers.

## 5. Conclusions

Articles in the academic literature and the business press have long argued for the benefits of a planned obsolescence strategy, where a firm designs a durable product to become obsolete after a certain period of use in order to induce consumers to make repeat purchases (Bulow 1986, Waldman 1996, Hendel and Lizzeri 1999, Waldman 2003, The Economist 2009). There are also several examples of firms pursuing such planned obsolescence strategies in practice (Slade 2006). However, the literature does not account for the conspicuous nature of some durable products,

where exclusivity-seeking consumer behavior becomes important. To the best of our knowledge, this paper is the first to incorporate snobbish consumer behavior for managing durable products and investigate its implications for new product introduction strategies.

At first glance, planned obsolescence appears to be a promising strategy when consumers value exclusivity since it curbs trade on the secondary market and reduces the volume products owned by consumers, thus making the product more exclusive. We show that it is in fact optimal for the firm to avoid planned obsolescence and instead offer high durability products. This is because durability and price act as complementary levers when selling to snobbish consumers: A higher durability commands a higher price, and increasing the price makes the product more exclusive. Our results provide theoretical support for some high durability strategies observed in practice. For example, BMW offers free maintenance services and extended warranty for the first four years, and emphasizing the high resale value of its cars as part of its marketing strategy - "It holds its value like it holds a corner" (BMW 2008) (also see NYT 2008, 2010). Similarly, a Swiss watch manufacturer advertises: "You never actually own a Philippe Patek, you merely look after it for the next generation."

Research has also discussed the benefits of technological obsolescence, where the firm introduces new and improved products to induce consumers to replace their existing products (Waldman 1993, Fishman et al. 1993, Waldman 1996, Fishman and Rob 2000, Nahm 2004). Moreover, the existing literature promotes both planned obsolescence and technological obsolescence and considers them to achieve the same goal, i.e., making old products less attractive and inducing replacement purchases (Waldman 2003). We show that these strategies are not interchangeable and that there is a crucial difference between these two forms of obsolescence in the presence of exclusivity-seeking consumer behavior: While a firm benefits from more technological obsolescence, planned obsolescence is no longer an attractive strategy. This is because the effect of a more improved product on the price is not only aligned with but also reinforces the role of price in making the product more exclusive. However, planned obsolescence naturally requires a firm to decrease the price, making the product less exclusive.

Our results highlight the importance of accounting for consumer behavior while introducing new durable products. They also reinforce the importance of focusing managerial attention on consumers earlier in the design process and using empathic design approaches to identify such latent behavioral traits (Leonard-Barton and Rayport 1997, Thomke and Von Hippel 2002, Business Week 2004).

While we made a number of assumptions to focus on the key trade-offs associated with our research question, our key findings are robust to several of these assumptions. As discussed earlier, our results continue to hold in the presence of heterogeneity in the consumers' exclusivity-seeking

behavior, the presence of a durability-dependent upfront design cost, a differential in the sensitivity to the exclusivity of new and used products, or the use of a two-period model (instead of an infinite-horizon model). An interesting direction for future research is to analyze a firm's new product introduction strategies in the presence of reference groups, i.e., where consumers experience a higher negative externality not only due to more consumers buying the same product, but also based on the identity of the consumers buying the product (Pesendorfer 1995, Amaldoss and Jain 2008).

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## Appendix

### A1. Derivation of Demand Functions and Proofs.

**Derivation of Demand Functions.** Let  $p^t \doteq (p_n^t, p_u^t)$ . A consumer of type  $\theta$  has the following discounted net utility maximization problem:  $V_\theta(a^0) = \max_{\{a^t(\theta), t \geq 1\}} \sum_{t=1}^{\infty} \rho^t U_\theta[a^t(\theta); a^{t-1}(\theta), p^t, Q_e^t]$ . Since the per-period net utility is bounded and the strategy space is finite, the above problem can be solved by deriving the Bellman equation for consumer  $\theta$  using backward induction (Blackwell 1965). The net present value functions  $V_\theta^t[a^{t-1}(\theta), p^t, Q_e^t]$  are a function of the consumer state  $a^{t-1}(\theta)$ , which completely specifies the sufficient information, and are recursively defined as  $V_\theta^t[a^{t-1}(\theta), p^t, Q_e^t] = \max_{a^t(\theta) | a^t(\theta) \mathbf{1}' = 1} U_\theta[a^t(\theta); a^{t-1}(\theta), p^t, Q_e^t] + \rho V_\theta^{t+1}[a^t(\theta), p^{t+1}, Q_e^t]$ . Define the reaction function  $R_\theta^t[a^{t-1}(\theta), p^t, Q_e^t] = a^t(\theta)^*$ , where  $a^t(\theta)^*$  is the solution to the previous equation.

The consumer's Bellman equation at the focal point can be written as  $V_\theta[a(\theta), p, Q_e] = \max_{a^t(\theta) | a^t(\theta) \mathbf{1}' = 1} \{U_\theta[R_\theta[a(\theta), p, Q_e]; a(\theta), p, Q_e] + \rho V_\theta[R_\theta[a(\theta), p, Q_e], p, Q_e]\}$ . Due to the periodicity of two for all consumer strategies at the focal point, permutations of the same pattern are not distinct. There are only 6 distinct strategies (BNBN, BNBU, BNI, BUBU, BUI, and II). Since the product lasts for two periods, a rational consumer who has a state of *BU* or *I* will choose the same action in the current period as she enters the period with no product. Thus, at the focal point,  $R_\theta[BU, p, Q_e] = R_\theta[I, p, Q_e]$ , which implies that BUI can be ruled out. We next prove that at the focal point, BNI cannot happen. Recall that the reaction function  $R_\theta[a(\theta), p, Q_e]$  is chosen to maximize  $U_\theta[s; a, p, Q_e] \equiv U_\theta[s; a, p, Q_e] + \rho V_\theta[s, p, Q_e]$ . Let us assume that BNI is a credible strategy, which implies that  $R_\theta[BN, p, Q_e] = I$  and  $R_\theta[I, p, Q_e] = BN$  for some  $\theta \in [0, 1]$ . Note that  $R_\theta[BN, p, Q_e] = I$  implies that  $p_u + \rho V_\theta[I, p, Q_e] > \theta - \lambda Q_e - p_n + p_u + \rho V_\theta[BN, p, Q_e]$  or  $\rho V_\theta[I, p, Q_e] > \theta - \lambda Q_e - p_n + \rho V_\theta[BN, p, Q_e]$ . However, the above equation implies



if  $p_n > \bar{p}$ . The equilibrium can be characterized as follows:  $D(p_n, \delta) = Q_e = \frac{\delta(1+\rho^2)+2\rho(1-p_n)}{\rho+\lambda(1+\rho)^2+\delta(1+\rho+\rho^2)}$ . The new product demand at the equilibrium is then given by  $D_n(p_n, \delta) = \frac{\delta(1+\rho^2)+2\rho(1-p_n)}{2(\rho+\lambda(1+\rho)^2+\delta(1+\rho+\rho^2))}$ .

*Solving the firm's pricing problem.* We can now solve the firm's pricing problem, where the firm maximizes the per-period profit  $\Pi(p_n, \delta) = (p_n - c(\delta))D_n(p_n, \delta)$ . Note that for the equilibrium to exist, we need  $p_n > \bar{p}$  to hold. We first solve the unconstrained version of the problem and then check to see if  $p_n > \bar{p}$  is satisfied. The second-order derivative of  $\Pi(p_n, \delta)$  with respect to  $p_n$  is strictly negative for  $\lambda \geq 0$ . Thus,  $\Pi(p_n, \delta)$  is strictly concave in  $p_n$ . Solving the first-order condition we obtain  $p_n^*(\delta) = \frac{\delta(1+\rho^2)+2\rho(1+c(\delta))}{4\rho}$ . Since  $\bar{p} - p_n^*(\delta) = -\frac{2\lambda(1+\rho^2)+\delta(3+\rho(6+2c\delta+3\rho))}{4\rho} < 0$ ,  $p_n^* > \bar{p}$  holds. Thus, a unique rational expectations equilibrium exists. Let  $\Pi(\delta) = \Pi(p_n^*, \delta)$  and  $D_n(\delta) = D_n(p_n^*, \delta)$ . It is straightforward to show that  $D_n(\delta) = \frac{\delta(1+\rho^2)+2\rho(1-c(\delta))}{4(\rho+\lambda(1+\rho)^2+\delta(1+\rho+\rho^2))}$  and  $\Pi(\delta) = \frac{\delta(1+\rho^2)+2\rho(1-c(\delta))}{16\rho(\rho+\lambda(1+\rho)^2+\delta(1+\rho+\rho^2))}$ , where  $D_n(\delta)$  decreases in  $\lambda$ .  $\square$

**Proof of Proposition 2.** The firm's profit evaluated at  $\rho = 1$  is given by  $\Pi(\delta) = \frac{(1+\delta-c(\delta))}{4(1+3\delta+4\lambda)}$ . The firm's problem is to maximize  $\Pi(\delta)$  by choosing  $\delta \in [0, 1]$ . By solving the first-order condition for the unconstrained problem,  $\Pi'(\delta) = 0$ , we get four roots given by  $r_1 = \frac{1-\sqrt{1+4c}}{2c}$ ,  $r_2 = \frac{1+\sqrt{1+4c}}{2c}$ ,  $r_3 = \frac{3-4c(1+4\lambda)-\sqrt{9+4c(-15+48\lambda+4c(1+\lambda)^2)}}{18c}$  and  $r_4 = \frac{3-4c(1+4\lambda)+\sqrt{9+4c(-15+48\lambda+4c(1+\lambda)^2)}}{18c}$ . It is straightforward to show that  $r_1 < 0$  and  $r_2 > 1$  for  $c \in [0, 1 + \delta]$  and since  $\Pi''(r_3) > 0$ ,  $r_3$  is a local minimizer. Thus, we have only three candidate solutions for  $\delta^*$ : 0,  $r_4$  and 1.

We will characterize  $\delta^*$  in the  $\lambda$ - $c$  space. We begin by finding the condition when  $\Pi(1) > \Pi(0)$ . Let  $x_1(c, \lambda) \doteq \Pi(0) - \Pi(1)$ .  $\partial x_1(c, \lambda)/\partial c = \frac{2c}{4+4\lambda} > 0$ ,  $x_1(0, \lambda) = -3\lambda/(2 + 10\lambda + 8\lambda^2) < 0$  and  $x_1(1, \lambda) = 3/(8 + 40\lambda + 32\lambda^2) > 0$ . Thus, there is a unique indifference curve defined by  $c = C_2(\lambda) \doteq 2 - \frac{2(1+\lambda)}{\sqrt{(1+\lambda)(1+4\lambda)}}$  where  $\Pi(0) = \Pi(1)$ ,  $\Pi(1) > \Pi(0)$  only if  $c < C_2(\lambda)$  and  $\Pi(1) \leq \Pi(0)$  otherwise. The condition  $c < C_2(\lambda)$  can be rewritten as  $\lambda > l_1(c) \doteq \frac{c(4-c)}{4(3-c)(1-c)}$ . We are now going to divide the  $\lambda$ - $c$  space in three different collectively exhaustive and mutually exclusive regions:  $c < C_1(\lambda) \doteq \frac{2+8\lambda}{13+16\lambda}$ ,  $C_1(\lambda) \leq c \leq 1/2$  and  $1/2 < c$ . The reason for choosing these regions is as follows: If  $c < C_1(\lambda)$  and  $r_4$  is real-valued,  $r_4 \geq 1$  and can be ruled out. Moreover,  $\lim_{\lambda \rightarrow \infty} C_1(\lambda) = 1/2$ . In each of these regions, we will determine  $\delta^*$  from the three candidate solutions (0,  $r_4$  and 1) by comparing  $\Pi(0)$ ,  $\Pi(r_4)$  and  $\Pi(1)$ .

First, if  $c < C_1(\lambda)$ , then  $r_4 \geq 1$  and is ruled out. We only need to compare 0 and 1. We know that  $\Pi(1) > \Pi(0)$ , i.e.,  $\delta^* = 1$  if  $\lambda > l_1(c)$  (or  $c < C_2(\lambda)$ ) and  $\delta^* = 0$  otherwise.

Second, if  $C_1(\lambda) \leq c \leq 1/2$ , then we can show that  $\Pi(0) > \Pi(1)$ . Thus, we only need to compare  $r_4$  and 0. However,  $r_4 > 0$  if and only if  $\lambda > \frac{-6-4c+3\sqrt{3}\sqrt{1+4c}}{16c}$ . If  $\lambda < \frac{-6-4c+3\sqrt{3}\sqrt{1+4c}}{16c}$ , then  $r_4$  is ruled out and  $\delta^* = 0$ . If  $\lambda > \frac{-6-4c+3\sqrt{3}\sqrt{1+4c}}{16c}$ , then  $\Pi(r_4) > \Pi(0)$  only if  $\lambda > l_2(c) \doteq \frac{3\sqrt{1+18c+108c^2+216c^3}-3-29c-16c^2}{8c(1+8c)}$ , where  $l_2(c) > \frac{-6-4c+3\sqrt{3}\sqrt{1+4c}}{16c}$ . Thus, if  $C_1(\lambda) \leq c \leq 1/2$ , then  $\delta^* = 0$  for  $\lambda < l_2(c)$  and  $\delta^* = r_4$  otherwise.

Finally, consider  $1/2 < c$ : If  $\lambda < 1/8$ , then  $r_4$  is not real valued and is ruled out. We only need to compare 0 and 1. We can show that  $1/8 < l_1(c)$ , which implies  $\lambda < l_1(c)$ . Thus,  $\Pi(0) > \Pi(1)$  for  $\lambda < 1/8$ , i.e.,  $\delta^* = 0$ . If  $1/8 \leq \lambda$ , then we can show that  $\Pi(r_4) > \Pi(0)$  and  $\Pi(r_4) > \Pi(1)$ , i.e.,  $\delta^* = r_4$ . Thus, if  $1/2 < c$ , then  $\delta^* = 0$  for  $\lambda < 1/8$  and  $\delta^* = r_4$  otherwise.

Putting all three cases from above together:  $\delta^* = 0$  if and only if  $\lambda \leq L(c)$ , where  $L(c)$  is defined as follows:

$$L(c) \doteq \begin{cases} l_1(c) & \text{if } c < C_1(\lambda), \\ l_2(c) & \text{if } C_1(\lambda) \leq c \leq 1/2, \\ 1/8 & \text{if } c < 1/2. \end{cases}$$

If  $\lambda > L(c)$ , then  $\delta^* > 0$ . If  $c < C_1(\lambda)$  also holds, then  $\delta^* = 1$ , otherwise  $\delta^* = r_4$ .  $\square$

**Proof of Proposition 3.** From Proposition 2,  $\delta^* = 0$  for  $\lambda \leq L(c)$ ,  $\delta^* = r_4$  for  $\lambda > L(c)$  and  $c > C_1(\lambda)$  (where  $C_1(\lambda)$  increases in  $\lambda$ ) and  $\delta^* = 1$  otherwise. Since  $r_4$  increases in  $\lambda$ ,  $\delta^*$  is non-decreasing in  $\lambda$ . It is straightforward to see that  $p_n$  is increasing in  $\delta$  (since  $c(\delta)$  increases in  $\delta$ ). Thus,  $p_n^* = p_n(\delta^*)$  is non-decreasing in  $\lambda$ . When  $\delta^* = 0$ ,  $D_n^* = D_n(0) = 1/(2 + 8\lambda)$ , which strictly decreases in  $\lambda$ . When  $\delta^* \in (0, 1)$ ,  $D_n^* = D_n(\delta^*)$  and it is straightforward to show that  $dD_n^*/d\lambda < 0$ . Finally, when  $\delta^* = 1$ ,  $D_n^* = D_n(1) = \frac{1-c}{8+4\lambda}$ , which strictly decreases in  $\lambda$ . Thus,  $D_n^*$  strictly decreases in  $\lambda$ .  $\square$

**Proof of Proposition 4.** For the sake of brevity, we do not replicate the entire derivation of the demand functions and the proof for determining the optimal new-product price. However, it is straightforward to show that the derivation of the demand functions and the solution for the firm's pricing problem can be obtained by replicating the analysis for  $u_n^t(\theta, Q_e^t) = (q^{t-1} + \alpha^t)\theta - \lambda Q_e^t$  and  $u_u^t(\theta, Q_e^t) = \delta^{t-1}q^{t-1}\theta - \lambda Q_e^t$  (details available on request). Let  $\delta^t = \delta \forall t$ . Recall that we restrict our attention to myopic, state-dependent, stationary policies for the firm. Under these assumptions, it can be shown that there exists a unique rational expectations equilibrium for the total volume of products owned by consumers, given by  $D^*(\alpha^t, p_n^* | q^{t-1}) = Q_e^*(\alpha^t, p_n^* | q^{t-1}) = \frac{q^{t-1}\delta(1+\rho^2)+2\rho(q^{t-1}+\alpha^t-p_n^*)}{2(\alpha^t\rho+\lambda(1+\rho)^2+q^{t-1}(\rho+\delta(1+\rho+\rho^2)))}$  (similar to Proposition 1). It can also be shown that at  $\rho = 1$ , the firm's profit at the optimal value of  $p_n^* = \frac{q^{t-1}\delta(1+\rho^2)+\rho(q^{t-1}+\alpha+k\alpha^2+c\delta^2)}{4\rho}$  is given by  $\Pi(\alpha|q) = \frac{(q(1+\delta)+\alpha-k(\alpha)-c(\delta))^2}{4(q(1+3\delta)+\alpha+4\lambda)}$ , where  $q$  is the quality of the previous product generation. Under our restrictions, the firm's problem is then given by  $\max_{\alpha \geq 0} \Pi(\alpha|q)$ . We obtain four different roots by solving the first-order condition  $d\Pi(\alpha|q)/d\alpha = 0$ , which are given by  $z_1 = \frac{1+\sqrt{1+4k(q(1+\delta)-c(\delta))}}{2k}$ ,  $z_2 = \frac{1-\sqrt{1+4k(q(1+\delta)-c(\delta))}}{2k}$ ,  $z_3 = \frac{1-4k(q(1+3\delta)+4\lambda)-\sqrt{1+16k^2(q(1+3\delta)+4\lambda)^2+4k(q(1+9\delta)+3c(\delta)+16\lambda)}}{6k}$  and  $z_4 = \frac{1-4k(q(1+3\delta)+4\lambda)+\sqrt{1+16k^2(q(1+3\delta)+4\lambda)^2+4k(q(1+9\delta)+3c(\delta)+16\lambda)}}{6k}$ . It is straightforward to show that since  $\Pi''(z_1|q) > 0$ ,  $z_1$  is a local minimizer, and  $z_2, z_3 < 0$  for all  $\delta, k, q, c > 0$ . Thus,  $z_1, z_2$  and  $z_3$  are ruled out. In addition, it can be shown that  $z_4 \geq 0$  for all  $\lambda, k, \delta, q, c > 0$  and  $\Pi''(z_4|q) < 0$ , i.e.,  $z_4$  is a local maximizer. Thus,  $\alpha^* = z_4 = \frac{1-4k(q(1+3\delta)+4\lambda)+\sqrt{1+16k^2(q(1+3\delta)+4\lambda)^2+4k(q(1+9\delta)+3c(\delta)+16\lambda)}}{6k} > 0$  is

the unique global maximizer for this problem. It is straightforward to show that  $\alpha^*$  increases in  $\lambda$ . Moreover, since  $p_n^*$  is increasing in  $\alpha$ ,  $p_n^*$  also increases in  $\lambda$ .  $\square$

## A2. Discussion of Assumptions.

**Presence of durability-dependent upfront design cost.** We can relax our model to include a durability-dependent fixed cost  $F(\delta) = f\delta^2$  instead of the durability-dependent marginal cost considered in our main analysis. It is straightforward to show that a fixed cost prompts the firm to seek a higher sales volume so that it benefits from a lower average cost of producing a unit of durability  $\delta$ . However, this benefit is not as strong as compared to the benefit from exploiting the exclusivity-seeking consumer behavior through lower sales. Thus, our qualitative results remain the same: The firm may prefer not to practice obsolescence and provide high durability coupled with a high price-low sales volume strategy.

**Differential in the sensitivity to the exclusivity of new and used products.** Let  $\lambda_u$  and  $\lambda_n$  be the sensitivity of all consumers to used and new products respectively. The externality is given by  $\lambda_u D_u^e + \lambda_n D_n^e$ . It can be shown that at the focal point, we have  $D_u = D_n = Q_e/2$ . Thus, we can write the externality as  $Q_e(\lambda_u + \lambda_n)/2$ , which can be rewritten as  $\lambda Q_e$ , where  $\lambda = (\lambda_n + \lambda_u)/2$ . With this definition of  $\lambda$ , our basic analysis for an equal sensitivity to exclusivity of new and used products holds.

**The Role of Heterogeneity in Consumers' Sensitivity to Product Exclusivity.** We assumed that all consumers are equally sensitive to product exclusivity. Let us relax our basic model to allow for heterogeneity in consumer behavior by assuming that a fraction  $\beta \in [0, 1]$  (independent of  $\theta$ ) of the consumers have sensitivity to exclusivity  $\lambda_h > 0$  (referred to as the more snobbish consumers), while the rest of the consumers have a lower sensitivity to exclusivity given by  $\lambda_l$  (referred to as the less snobbish consumers), where  $0 < \lambda_l < \lambda_h$ . The firm has to decide whether it would prefer to set the durability and price such that either both consumer types or only one type buy the product.<sup>9</sup>

Let the volume of products owned by the consumers from the more snobbish segment be  $D^\beta$  and that from the less snobbish segment be  $D^{1-\beta}$ . The total volume of products owned by consumers is given by  $D(p, \delta; Q_e) = D^\beta(p, \delta; Q_e) + D^{1-\beta}(p, \delta; Q_e)$ . The derivation of the demand functions  $D^\beta(p, \delta; Q_e)$  and  $D^{1-\beta}(p, \delta; Q_e)$  is identical to the homogeneous case except with  $\lambda = \lambda_h$  or  $\lambda = \lambda_l$  (details available upon request). The supply of used products on the secondary market is given

<sup>9</sup> Note that in order to focus on the effect of heterogeneity in consumers' snobbishness, we still restrict our attention to the firm introducing only one product and not a line of products to effectively segment the market. Relaxing this assumption to allow the firm to design two products to segment the market is intractable, especially due to the heterogeneity in the willingness-to-pay for the quality of the product. However, we conjecture that our qualitative insights may still hold, i.e., that as the snobbishness of the target segment for any product in the product line increases, the firm may offer a higher durability product to that segment.

by  $\beta(1 - \Theta_1)I_\beta + (1 - \beta)(1 - \Theta_1)I_{1-\beta}$  and the demand for them is given by  $\beta(\Theta_2 - \Theta_3)I_\beta + (1 - \beta)(\Theta_2 - \Theta_3)I_{1-\beta}$ , where  $I_\beta$  and  $I_{1-\beta}$  are indicator functions for whether the  $\beta$  and the  $1 - \beta$  segment purchase the product or not, respectively. The market-clearing price is then implicitly given by equating the supply and demand of used products. Evaluating at the market-clearing price, it is straightforward to show that if  $\lambda_h > \lambda_l \geq 0$ , the less snobbish consumers will always buy the product. Thus, if only one type of consumers buy the product, it will be to the less snobbish consumers (since they always face a lower externality).

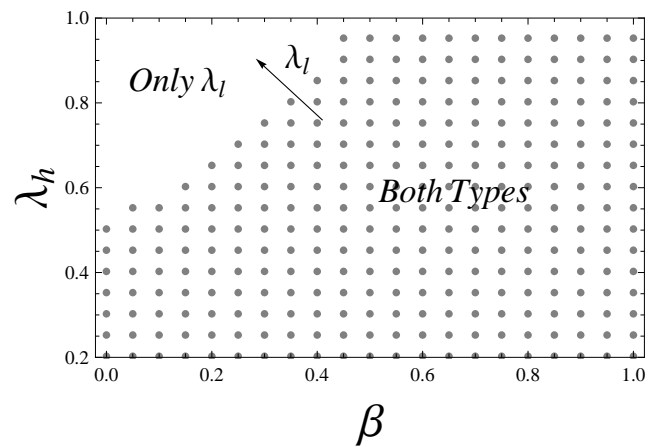
We can also show that similar to the homogeneous case, a unique rational expectations equilibrium exists only if  $p_n > \bar{p}'$ . The optimal price is given by  $p_n^*(\delta) = \frac{\delta(1+\rho^2)+2\rho(1+c(\delta))}{4\rho}$ , where  $p_n^* > \bar{p}'$ . Moreover, it can be shown that if  $\delta < \frac{-1+4(1-\beta)(\lambda_h-\lambda_l)}{3}$ , only the less snobbish consumers buy the product, otherwise both types of consumers buy the product. If  $\lambda_h < \frac{1}{4(1-\beta)} + \lambda_l$ , then  $\delta < \frac{-1+4(\lambda_h-\lambda_l)(1-\beta)}{3}$  cannot hold for  $\delta > 0$  and both types of consumers buy the product. However, if  $\lambda_h \geq \frac{1}{4(1-\beta)} + \lambda_l$ , then  $\delta < \frac{-1+4(\lambda_h-\lambda_l)(1-\beta)}{3}$  can hold for  $\delta > 0$  and either both types or only the low type will buy the product.

Under  $\lambda_h < \frac{1}{4(1-\beta)} + \lambda_l$  (where both types buy the product), the firm's per-period profit evaluated at the optimal price  $p_n^*$  is given by  $\Pi(\delta) = \frac{(1+\delta-c(\delta))^2}{4(1+3\delta+4(\beta\lambda_h+(1-\beta)\lambda_l))}$  or  $\Pi(\delta) = \frac{(1+\delta-c(\delta))^2}{4(1+3\delta+4\bar{\lambda})}$ , where  $\bar{\lambda} = \beta\lambda_h + (1 - \beta)\lambda_l$ . This is identical to the profit under the homogeneous case, with  $\lambda = \bar{\lambda}$ . Thus, from Proposition 2,  $\delta^* = 0$  if  $\bar{\lambda} \leq L(c)$ ,  $\delta^* = r_4$  for  $\bar{\lambda} > L(c)$  and  $c > C_1(\bar{\lambda})$ , and finally  $\delta^* = 1$  for  $\bar{\lambda} > L(c)$  and  $c < C_1(\bar{\lambda})$ . Moreover, the optimal durability and the new-product price are non-decreasing in  $\bar{\lambda}$ , which implies that  $\delta^*$  and  $p_n^*$  increase in  $\lambda_h$ ,  $\lambda_l$  and  $\beta$  (from Proposition 3).

Under  $\lambda_h \geq \frac{1}{4(1-\beta)} + \lambda_l$  (where either both types buy the product or only the less snobbish consumers buy the product), the per-period profit evaluated at the optimal price  $p_n^* = \frac{\delta(1+\rho^2)+2\rho(1+c(\delta))}{4\rho}$  is given by  $\Pi(\delta) = \frac{(1-\beta)(1+\delta-c(\delta))^2}{4(1+3\delta+4(1-\beta)\lambda_l)}$  for  $0 \leq \delta < \frac{-1+4(\lambda_h-\lambda_l)(1-\beta)}{3}$  and  $\Pi(\delta) = \frac{(1+\delta-c(\delta))^2}{4(1+3\delta+4(\beta\lambda_h+(1-\beta)\lambda_l))}$  otherwise. In this condition, solving for the optimal durability is analytically intractable. However, we can numerically optimize the per-period profit evaluated at the analytically determined optimal price to find the optimal durability for an extensive range of parameters  $\lambda_h$ ,  $\lambda_l$ ,  $c$  and  $\beta$ .

Analyzing these results, we obtain the following insights for the firm's optimal durability under  $\lambda_h \geq \frac{1}{4(1-\beta)} + \lambda_l$ : Only the less-snobbish consumers buy the product when the snobbishness of the more snobbish consumers is sufficiently high and they constitute a small fraction of the market (see Figure 4). The region where only the less snobbish consumers buy the product decreases in  $\lambda_l$  (see Figure 4). This is because as  $\lambda_l$  increases, they become similar to the more snobbish consumers, which makes the firm prefer selling to both types of consumers. Moreover, it is straightforward to see that if only the less snobbish consumers buy the product, the optimal durability and new-product price are non-decreasing in  $\lambda_l$ .  $\square$

**Figure 4** Role of Heterogeneity in consumers' sensitivity to exclusivity in the firm's strategy, where  $c = 0.7$  and  $\lambda_l = 0.2$ . Only the less snobbish consumers buy the product if  $\lambda_h$  is sufficiently large and  $\beta$  is sufficiently low. Otherwise both types buy the product.



**Comparisons with a two-period model.** We used an infinite-horizon model, which simplifies our analysis and allows us to obtain closed-form results. Nevertheless, our results are similar under a two-period model: The firm's optimal durability is non-decreasing in  $\lambda$  and as one can see from Figure 5 (where panel b is obtained numerically instead of analytically), the firm's optimal design strategy is similar under the infinite-horizon and two-period models. The details of the analysis for the two-period model are available upon request.  $\square$

**Figure 5** Comparison of the optimal design strategy under an infinite-horizon model (panel A) and a two-period model (panel B)

