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The Effects of Sensitization and Habituation in Durable Goods Markets

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We develop a model to study the impact of changes in price sensitivity on the firm as it introduces multiple generations of a durable product where unit costs are a convex function of quality. We incorporate the psychological processes of sensitization and habituation into a model of discretionary purchasing of replacement products motivated by past experience. When price sensitivity decreases with each purchase (sensitization), the myopic firm offers a higher quality product at a much higher price with each generation. When price sensitivity increases with each purchase (habituation), the myopic firm engages in price skimming. When sensitization is followed by habituation, the myopic firm eventually provides higher quality than the market is willing to pay for, leading to a steep drop-off in sales and profits. The actions of the forward-looking firm depend on the discount rate. A firm with a low discount rate builds its customer base before offering a higher quality and higher priced product. In contrast, a firm with a high discount rate quickly increases price and quality following the same path to falling profits of the myopic firm. These results provide insight into the firm and consumer behaviors underlying the phenomenon of "performance oversupply" identified in the innovation literature.

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The Effects of Sensitization and Habituation in Durable Goods Markets

1. Introduction

Owning and using a durable product can change the way consumers feel about it. As they gain experience, their interests may change. For example, Youn, Song and MacLachlan (2007) find that brand preferences and price sensitivities for rock climbing equipment evolve as consumers gain more experience with the sport over time. Such changes influence the demand for replacement products and should be of great interest to managers.

We often observe that consumers replace a durable good not because of failure, but to gain greater performance. There is ample anecdotal evidence of this type of replacement buying. Some weekend golfers replace their drivers every season with the latest version, seeking a few more yards off the tee. Cyclists replace a functioning bike component with one that is marginally lighter, but certainly much more expensive. Audiophiles may buy a new piece of equipment to improve the reproduction of sounds outside the range of human hearing. Such behavior is not limited to individuals. Every year, auto racing teams spend increasing amounts of money seeking very small incremental improvements in performance.

This is a very interesting yet understudied area of dynamic consumer behavior. When consumers often seek out a more advanced version of a durable product before their existing product has reached the end of its useful life, such replacement purchases are completely “discretionary” (Bayus 1992). However, this motivation for a replacement purchase is very different from those identified in the existing literature on durable goods, e.g. low prices (Bayus 1988), styling (Bayus 1991) or changed family circumstances (Gabor and Granger 1972; Pickering, 1975). In this study, product performance is the key motivator for discretionary replacement buying. We assume that, when buying a replacement product, consumers will only consider a product that offers performance superior to the product they already own.

This type of discretionary repurchasing raises a number of interesting and important questions. For example, how are the optimal levels of price and quality affected by decreases in consumer price sensitivity? What happens if a consumer’s price sensitivity increases after multiple replacement purchases? How does the requirement for better and better products over time affect the nature of the market (sales patterns, level of repeat purchases, profits, etc.)?

To address these questions, we build on recent theoretical research by Watheiu (2004) who considered the impact of periodic consumption on the price sensitivity on frequently consumed products (e.g. food). We examine how decreases in price sensitivity (sensitization) or increases in price sensitivity (habituation) affect the optimal price and quality over time for a myopic firm selling durable products to new and experienced buyers. We explore the implications for the firm of sensitization followed by the onset of habituation for the myopic and forward-looking firm.

We find that when price sensitivity decreases with each purchase (sensitization), the myopic firm should offer a higher quality product at a much higher price with each generation. When price sensitivity increases with each purchase (habituation), the myopic firm will engage in price skimming. When sensitization is followed by habituation, the myopic firm eventually provides higher quality than the market is willing to pay for, leading to a steep drop-off in sales and profits. The actions of the forward-looking firm depend on the discount rate. A firm with a low discount rate builds its customer base before offering a higher quality and higher priced product. In contrast, a firm with a high discount rate quickly increases price and quality following the same path to falling profits of the myopic firm. These results provide insight into the firm and consumer behaviors underlying the phenomenon of “performance oversupply” identified in the innovation literature (Christensen, 1997).

In order to incorporate these types of changes in consumer preferences, we use a very different approach rather than the typical innovation model (Bass 1969; Teng and Thompson 1996) and the traditional models of durable good monopolies (Gul, Sonneschein, and Wilson, 1986; Tirole, 2003). First, price and quality as well as consumer heterogeneity are endogenous. Second, we model first purchases and repeat purchases using a random utility (i.e. logit) formulation (as in Kim, Srivastava and Han 2001). Third, and most important, we incorporate a “replacement rule” to model the effect of owning earlier versions on replacement purchases. Usually, replacement purchases are based on a product’s useful life (e.g. Kamakura and Balasubramanian, 1987; Bayus, 1988). In our model, experienced consumers only consider repurchasing if the product available is better than the one they already own (Rogers 1995). Therefore, in order to sell to experienced buyers, the firm must offer a better product.

While very realistic, this assumption comes at the price of model tractability. The replacement rule introduces significant discontinuities into the objective function for the firm. These discontinuities preclude a closed-form model solution. Therefore, following the example of Dasu and Tong (2010) among others, we analyze a series of multi-period scenarios to ascertain the effects of decreasing and/or increasing price sensitivities on the firm's optimal price, quality and profits over a fixed number of product generations.

Our study builds on the current research on how consumer preferences change with experience e.g.: Kim, Srivastava, and Han 2001; Mallik and Chhajed, 2006; Matsubayashi and Yamada, 2008; Youn, Song and MacLahan 2007), ours is the first model we know of that focuses on the important issue of improved performance as a determinant of discretionary replacement purchasing. In the next section, a brief literature review is followed by the basic model assumptions. The results of our model analyses are then presented in detail. The final section summarizes our contributions and offers directions for future research.

2. Brief Literature Review

Much of the prior research on the evolution of consumer preferences focuses on consumer packaged goods. These studies seek to empirically determine the direction and extent of changes in price sensitivity over time (e.g., Heilman, Bowman and Wright 2000; Erdem and Sun 2001). An exception is Youn, Song and MacLahan (2007) who find that, as consumers gain experience with rock climbing, their price sensitivity decreases. At the same time, experienced climbers tend to prefer shoes that are lighter, more flexible and provide greater sensitivity leading to changes in brand preferences.

Recent theoretical work by Wathieu (2004) examines the impact of consumption over time on price sensitivity. Using results from the behavior psychology literature (e.g. McSweeney, Hinson and Cannon, 1996), Wathieu (2004) suggests that consumption over time could lead price sensitivity to evolve along one of two distinct paths: sensitization or habituation. If it does occur, sensitization is usually associated with the initial stages of consumption. At this stage, customers become increasingly interested in consuming the product as they experience the promised benefits. Sensitization results in a decrease a price sensitivity as they continue to consume it over time (Wathieu 2004). The sensitization stage has parallels with addictive processes since current consumption leads to an increase in future consumption (Becker and Murphy 1988).

In the case of some durable products, sensitization is a by-product of increased experience with the product which, in turn, increases a consumer's expertise and familiarity (Hoch and Deighton 1989) while reducing perceived risk. Zhao, Meyer and Han (2005) find that consumers are often attracted to new versions of products that offer additional features, even if these features are never used.

Over time, continued consumption usually leads to habituation. As consumers get accustomed to consuming the same product over and over, their interest may wane and their price sensitivity increases. In markets for frequently purchased packed goods, consumers may engage in variety-seeking behavior (McAlister and Pessemier, 1982) or they may stockpile the product when it is on sale. For frequently purchased products, the onset of habituation depends on frequency and intensity of consumption (Wathieu, 2004).

For some durable products, increased price sensitivity could occur with the first purchase. For example, Thompson, Hamilton and Rust (2005) found that consumers can be overwhelmed by the complexity of new products with a great variety of features. Their experimental work finds that consumers can suffer from "feature fatigue" which reduces their interest in "new and improved" models of products already owned.

In our study, we model how the influences of sensitization and habituation separately affect a myopic firm's decisions regarding price and quality when selling to new and experienced customers over multiple generations. We then investigate how sensitization followed by habituation affects the decisions of myopic and forward-looking firms.

3. Model Formulation

In order to isolate the effects of changes in price sensitivity on repeat purchases, we limit our analysis to the situation of a monopolist setting the profit maximizing price and quality of a single product over a number of generations. This is consistent with the analytical models of a durable goods monopolist introducing sequential innovations (e.g., Dhebar 1994; Kornish, 2001).

We further depart from the existing literature on "upgrade" purchasing wherein the firm can price discriminate based on previous purchasing (Fudenberg and Tirole 1998). We assume that, in a given generation, the firm charges the same price to and provides the same quality level for all consumers.

The monopolist's profit in generation ***g*** is determined by:

(1) $$\pi_g = (P_g - MC_g)\, S_g$$

In generation ***g***, P_g is price, MC_g is marginal cost, and S_g is sales. Sales in a given generation (S_g) are the sum of the purchase probabilities for all consumers that purchase in generation ***g*** (see, for example, Kim, Srivastava and Han 2001). These probabilities are determined at the individual consumer level by the current price and quality as well as the consumer's purchase history, i.e. the quality levels of products already purchased. As in Moorthy and Png (1992), the quality variable represents all non-price product attributes such as performance, reliability, durability, and so on (Garvin, 1987).

The extant research on multi-generational durables such as software, computer chips, etc. (see e.g. Pangburn and Sundaresan 2009) assumes that the firm faces very high development costs and very low marginal costs[2]. In such markets, firms usually practice skim pricing (e.g. Beskano and Wilson 1990). By setting initial prices high and reducing them later, the firm maximize profits via price discrimination. However, in such markets, consumers learn the patterns of price changes and build expectations about future price reductions (see, e.g., Song and Chintagunta 2003). Some forward-looking consumers may delay purchasing and wait for the price to fall. The composition of the market with regard to the number of consumers who will purchase immediately versus waiting has an important impact of the firm's pricing over time. In models where quality is endogenously set, fixed spending on R&D determines the level of quality offered to customers (Fishman and Rob, 2000).

In our model, we consider a very different relationship between costs and quality. As noted above, the extant literature generally assumes that, in order to attain a desired level of quality, the firm must invest in a given level of fixed investment. In our model, the influence of quality on costs is variable. Specifically, we assume that unit marginal

[2] In other situations, it is assumed that costs are lower over time, due to learning or experience curve effects, as the cumulative number of units produced increases (e.g., Teng and Thompson 1996).

cost is a fixed quadratic function of quality. This assumption is consistent with empirical studies of cost behavior (e.g., Foster 1994) as well as prior analytical research (Matsubayashi and Yamada, 2008, Balachander and Srinivasan 1994, Moorthy 1988). As a simplifying assumption, we assume zero fixed costs (e.g. Kim and Chhajed, 2000; Mallik and Chhajed, 2006).

Unit marginal cost as a function of quality is given by:

(2) $$MC_g(X_g) = r_0 + r_1 X_g + r_2 X_g^2$$

where X_g is the quality level for generation **g**. The cost intercept and coefficients are represented by r_0, r_1 and r_2 respectively are fixed to reflect a constant technology frontier. This cost assumption has important implications for the consumer. Since providing higher levels of quality cost the firm more, consumers should not expect that prices will fall over time[3].

In every period, the monopolist chooses quality (X) and price (P) to solve:

(3) $$\underset{X,P}{Max}\left(P_g - MC_g\right)S_g$$

Note that generation *g* is of undetermined length. It could be months or years (the optimal timing of product generations is discussed in Druehl, Schmidt and Souza 2009). Each period represents a single generation of the durable product.

3.1 Consumer Demand Model

Our model of consumer demand is based on a random utility model and involves both first purchases and discretionary replacements (e.g., Kim, Srivastava and Han, 2001).

The utility μ_g of a product in generation *g* is given by:

(4) $$\mu_g = \Phi_0 + \beta X_g - \alpha_c P_g$$ where

- X_g is the quality level for generation *g*

[3] However, it is important to note that almost all of the research on "forward looking" consumers is usually based on one of two assumptions, either fixed costs are very high and there are differences in price sensitivity across consumer (leading to price discrimination over time) or that costs fall over time due to experience curve effects. We are looking at very different situation in which increases in quality come at a high cost. It is unclear whether consumers anticipate price increases or decreases as new generations of the product are introduced. Therefore, we assume that consumers are myopic in the sense that they do not anticipate price changes over time.

- Φ_0 is a fixed market-level propensity for purchase in this category[4].
- β represents the consumer's sensitivity to quality (Nevo 2000)
- P_g is the price of the product in generation *g*
- α_c is the price sensitivity, which changes according to the number of purchases (*c*) a consumer has made.

It is important to note that price sensitivity changes due to the number of purchases made by the consumer and not due to the passage of time. In the first period, every consumer has the same price sensitivity. With each purchase, a consumer's price sensitivity changes, decreasing under sensitization and increasing under habituation. For those consumers who have not yet purchased in the category, their price sensitivity stays constant until such time that a purchase is made.

This approach allows us to model customers who are making an initial purchase as having different price sensitivities than those customers who are considering a discretionary repeat purchase. For example, under sensitization, a consumer who has made a purchase would have a lower price sensitivity when evaluating the current generation product than a consumer who has not yet purchased in the category. The lower price sensitivity of repeat purchasers is a reflection of their increasing interest in the product category which arises from product ownership and usage (Hoch and Deighton 1989).

The probability of purchase $Pr(\alpha_c, X_g, P_g)$ for consumers in generation *g* with price sensitivity α_c given *c*, the number of purchases already made, is formulated as a logit model. After having purchased the product, consumers will only consider repurchasing if the quality of the current generation product is superior to the quality of product purchased most recently. We refer to this constraint as a "replacement rule." This condition reflects the situation in which replacement will not be considered until a better, more capable, or more powerful version becomes available (Rogers 1995).

At the individual level, the probability of purchase is given by:

[4] The fixed Φ_0 assume there are no social contagion or word of mouth influences on purchasing.

$$(5) \quad \Pr(\alpha_c, X_g, P_g) = \begin{cases} \dfrac{e^{\mu_g}}{1+e^{\mu_g}} & if \quad X_g > X_{of\ last\ purchase} \quad or \ g = 1 \\ 0 \ \ otherwise \end{cases}$$

The sales (S_g) in any generation ***g*** are equal to the sum of all these probabilities across all consumers. As in prior research on multi-generational purchasing (e.g. Dhebar, 1994; Kornish, 2001), we assume consumers buy no more than one unit in each generation and there is no secondary market for used products.

3.2 Consumer Price Sensitivity Dynamics

Before their first purchase, we assume that all consumers have the same price and quality sensitivities. In the first generation, all consumers decide on whether or not to buy the product for the first time. At the end of this generation, there are two different groups of consumers. The first consists of those who bought the product. Their experience with the product has changed their price sensitivity. The size of this group is given by ($\Pr(\alpha_0, X_1, P_1)$) and their price sensitivity changes to α_1. The second is the group of customers that did not buy it, with size ($1- \Pr(\alpha_0, X_1, P_1)$) and price sensitivity stays as α_0. This is illustrated in Figure 1.

Insert Figure 1 here

In the second generation, the group of consumers that did not purchase yet decides whether to purchase or not for the first time with probability $\Pr(\alpha_0, X_2, P_2)$ while the group of consumers that already purchased once decides whether to repurchase or not with probability $\Pr(\alpha_1, X_2, P_2)$. Recall that members of this latter group will only consider repurchasing if the quality of the new generation is higher than the product he or she already owns.

At the end of the second generation, there are four types of customers. Their price sensitivity varies from α_0 to α_1 and α_2 according to the total number of purchases each has made in previous periods. This process is repeated for all generations. The total sales in any generation ***g*** is given by the sum of all probabilities across all 2^g segments of consumers. Each segment is associated with a different price sensitivity <u>and</u> a different level of quality necessary to motive replacement buying.

3.3 Optimality Conditions for the Myopic Firm

We first assume that the firm is myopic. The firm sets its price and quality level to maximize profit in a given generation without regard to the future. (Later, we relax this assumption to allow for forward-looking behavior). All consumers are exposed to the optimal price P_g^* and quality X_g^* in generation $\boldsymbol{g}$. The objective function π_g is given by:

(6) $$\pi_g = (P_g - MC_g)\, S_g$$

where: $$MC_g(X_g) = r_0 + r_1 X_g + r_2 X_g^2$$

$$S_g = \Sigma_c Pr(\alpha_c, P_g, X_g)$$

$$\Pr(\alpha_c, X_g, P_g) = \begin{cases} \dfrac{e^{\mu_g}}{1+e^{\mu_g}} & if \quad X_g > X_{of\ last\ purchase} \ or\ g = 1 \\ 0 \quad otherwise \end{cases}$$

In the first period, all purchases by consumers are initial purchases. This simplifies the expression S1 as follows:

(7) $$S_1 = \frac{e^{\mu_1}}{1+e^{\mu_1}} = \frac{e^{\Phi_0 + \beta X_1 - \alpha_0 P_1}}{1+e^{\Phi_0 + \beta X_1 - \alpha_0 P_1}}$$

The first order conditions for the maximization of π_1 are given by:

(8) $$\frac{\partial \pi_1}{\partial P_1} = S_1 + (P_1 - MC_1)\frac{\partial S_1}{\partial P_1} = 0$$

(9) $$\frac{\partial \pi_1}{\partial X_1} = -S_1 \frac{\partial MC_1}{\partial X_1} + (P_1 - MC_1)\frac{\partial S_1}{\partial X_1} = 0$$

In an appendix (available from the authors), we show that any level of price and quality (P_1*, X_1*) satisfying these conditions is a unique maximum for π_1

In subsequent generations, the firm's profit function changes from one that is well-behaved and continuous to one characterized by discontinuities. These discontinuities are the result of the replacement rule. Recall that an experienced customer will only consider a replacement purchase if the quality of the current generation product is superior to that of the product the customer last purchased. For example, in the second generation, if the firm considers quality levels below the optimal level associated with the first period (i.e., X_1^*), demand will only come from those consumers who have yet to purchase. However, above this value, the profit function includes repeat purchases. Due to this discontinuity, we have a piece-wise continuous objective function. In Figure 2, we illustrate the discontinuity in profit function at the second period, given the optimal quality level of the first period (X_1^*).

Insert Figure 2 about here

The objective function for the firm has no closed form solution given the two influences of past purchasing on the optimal price and quality for a given generation of the product. First, the number of purchases made by each individual consumer affects the price sensitivity. Second, depending on the generation in which a given consumer made his or her last purchase, each will have a different quality hurdle for repurchasing.

Due to the discontinuities illustrated in Figure 2, we have to consider the quality levels of products sold in the past. Each level of quality creates a discontinuity in the objective function, and separates the quality solution space into 2^g subspaces where the number of generations g is also the number of quality levels of products sold in the past. To identify the optimal price and quality, we identify the 2^g prices and quality levels that maximize the objective function over each of the 2^g sub-spaces. We then compare the level of the objective function for all of the sub-spaces to determine the global maximum.[5]

3.4 Optimality Conditions for the Forward-Looking Firm

In this section, we formulate the forward-looking monopolist's problem as a multi-period optimization. At the start of the first period, the forward-looking firm considers all possible combinations of price and quality. The firm also anticipates the consumers' purchase decisions for each possible combination of price and quality for all periods. Then, given that set of information, the firm picks the price trajectory ($P_{g=1}$ .. $P_{g=G}$) and quality trajectory ($X_{g=1}$ .. $X_{g=G}$) for all generations that yield the largest overall profit. Given that we are assuming the firm is forward looking, there is no need to revise the decision after the first period, as all consumers will behave as expected.

As the number of generations grows, this problem quickly becomes very difficult to solve because it has <u>two</u> processes subject to the curse of dimensionality (Bellman, 2003). First, the number of price and quality trajectories grows exponentially with g. Second, the number of consumer groups (shown in Figure 1) also grows exponentially with g.

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[5] The myopic optimization method was implemented in Mathematica 5.1; code is available from the authors

For example, assume a firm is deciding among three quality levels, and four price levels. In the first period, the firm will face 3 x 4 = 12 combinations of price and quality levels. In the second period, there will be 12^2=144 combinations. In the fifth period, there will be 12^5=248,832 combinations of price and quality levels. Additionally, by the fifth period there will be 2^5 = 32 groups of consumers. Thus, in a simple multi-period optimization with five generations, the firm has to compute and keep track of 248,832 combinations of price and quality for 32 groups of consumers.

Finding the Optimal Price and Quality Trajectory

Each of these 12^g x 2^g cells indicates purchase probabilities $Pr(\alpha_c, X_g, P_g)$ for all consumer groups, for all combinations of quality and price levels, and for all generations. To find $[P^*_1 .. P^*_G]$ and $[X^*_1 .. X^*_G]$, the firm must do three more steps, conditional on each one of the 12^g price and quality trajectories. First, the firm must compute sales and partial profits for each generation, both conditional on price and quality trajectories. Second, it must compute the total profit, also conditional on a price and quality trajectory. Finally, the firm just chooses the price and quality trajectory that yields the highest total profit $\{\pi \mid P_1 .. P_G, X_1 .. X_G\}$.

Conditional sales, $\{ S_g \mid P_1 .. P_G, X_1 .. X_G\}$, are simply the summation of all purchase probabilities $\{ Pr(\alpha_., X_g, P_g) \mid P_1 .. P_G, X_1 .. X_G\}$ <u>within each generation</u>, <u>across all consumer groups</u> with different consumption levels. Partial profits are computed for each generation as $\{\pi^{partial}_{g,Xg,Pg} \mid P_1 .. P_G, X_1 .. X_G\} = (P_g - MC_g)\{S_g \mid P_1 .. P_G, X_1 .. X_G\}$. Total profit conditional on a trajectory $\{\pi \mid P_1 .. P_G, X_1 .. X_G\}$ is simply the discounted summation of $\{\pi^{partial}_{g,Xg,Pg} \mid P_1 .. P_G, X_1 .. X_G\}$ across all G generations for that trajectory.

A Complete Representation of the Solution of the Multi Period Problem

The Bellman equation accounts for profits from acting optimally in current generation as well as the discounted profits from acting optimally in the future.

Profits in generation g for consumer with c past purchases are based on the probabilities of purchase $Pr(\alpha_c, X_g, P_g)$ at generation g for consumer with number of purchases c, the price P_g that consumer paid at that generation, marginal costs, and a replacement variable $\Delta_{g,c}$ that indicates if the purchase actually happened or not at that point. Thus, we write the immediate reward $I_R(g,c)$ as:

(10) $I_R(g,c) = \eta_{c,g}(P_g - MC_g)\Delta_{g,c}$

where, for ease of exposition, let $\eta_{c,g} = \Pr(a_c, X_g, P_g)$ be the probability of the customers with c past purchases buying the product at price P_g and quality X_g. Marginal cost MC_g are a function of quality (X_g). The term $\Delta_{g,c}$ is a replacement indicator.

(11) $$\Delta_{g,c} = \begin{cases} 1 & \text{if } X_h < X_g \\ 0 & \text{otherwise} \end{cases}$$

Where *h* is the generation in which the last purchase occurred for these consumers and, therefore, X_h is the quality level of the product the consumers already own.

The discounted reward for continuing to act optimally in the future has two parts. First, if a consumer made a purchase [probability given by $\Pr(\alpha_c, X_g, P_g)$], his or her price sensitivity a_c is updated to α_{c+1}. If the consumer did not make a purchase [probability given by 1- $\Pr(\alpha_c, X_g, P_g)$], his price sensitivity stays as α_c. In both cases we discount future profits by a rate a=1/R which reflects how much the firm values future profits. So, our continuation reward has two terms as follows:

(12) $$\left(\frac{1}{R}\right)\eta_{c,g}\pi(g+1,c+1,\frac{1}{R}) + \left(\frac{1}{R}\right)[1-\eta_{c,g}]\pi(g+1,c,\frac{1}{R})$$

Having derived the immediate reward (eq. 10) and the continuation reward (eq.12), we are able to derive the Bellman equation as follows:

(13) $$\pi(g,c,\frac{1}{R}) = Max_{X_g,P_g}\left\{\begin{matrix} \eta_{c,g}(P_g - MC_g)\Delta_{g,c} + \\ \left(\frac{1}{R}\right)\eta_{c,g}\pi(g+1,c+1,\frac{1}{R}) + \left(\frac{1}{R}\right)[1-\eta_{c,g}]\pi(g+1,c,\frac{1}{R}) \end{matrix}\right\}$$

The solution to equation 13 is the set of price and quality levels for generations 1..G that maximize overall profits[6] given all generations and groups of consumers with different consumption history.

4. Study Design

We wish to understand the potential effects of sensitization and habituation (as well as the replacement rule) on the optimal price and quality of a durable good across multiple generations. To this end, we focused on two forms of firm decision making:

[6] The forward-looking optimization method was implemented in C#. Code is available from the authors.

myopic and forward-looking. In the first set of scenarios, we assume that firms are myopic. We examine the separate effects of sensitization or habituation. This is followed by a scenario wherein sensitization is followed by habituation.

In the second set of scenarios, we assume that the firm is forward-looking. We concentrate on the most interesting scenario where sensitization is followed by habituation. For these analyses, we vary the rate at which future profits are discounted. This allows us to better compare the outcomes under the assumptions on firm behavior (i.e. myopic versus forward-looking).

4.1 Baseline Numerical Solution

In order to compare results across different situations of changing price sensitivities (based on purchase history), we identified a set of parameters that creates a realistic baseline (e.g., positive profits) against which we could analyze relative movements. For the cost parameters, we used the following: (r_0= 1, r_1= 0.4, r_2= 0.05). This cost function allows some influence of the quadratic term on marginal costs. The initial price and quality sensitivities were set to unity ($\alpha_0 = \beta_0 = 1.0$).

4.2 Scenarios for Myopic Firm

Our analysis departs from the baseline where all purchases are first purchases (i.e., in the first generation) and all coefficients are fixed (the parameters were presented in the previous section). We analyzed three scenarios by changing separately price sensitivity as shown in Figure 3.

Insert Figure 3 here

We ran our analysis over ten generations. In scenario A, we decrease price sensitivity for the individual at two different rates (i.e., -0.05, -0.10) each time a purchase is made. In scenario B, we increase price sensitivity linearly at the rate of 0.10 for every purchase[7]. The baseline market-level propensity for category purchase was Φ_0= -1.79. The optimal price and quality for the first generation is X*= 6 and P* = 6.3. This results in a profit of 10.9 and a first generation penetration rate of 10%. This level of market adoption is consistent with empirical research on innovation diffusion (Mahajan, Muller and Wind 2000).[8]

[7] There are no differences beyond rounding errors for different increases in price sensitivity.

[8] We also tested other initial levels of α_0, β_0, and Φ_0. The results differ from those presented here in their

Scenario C is the sensitization-habituation scenario. Here, the price sensitivity is decreasing during the first periods, corresponding to the sensitization stage. The minimum price sensitivity is reached either after the third or sixth purchase. At this point, habituation begins and price sensitivity increases with every subsequent purchase. For this scenario, the per-purchase rate of change is -0.10 for sensitization and +0.10 for habituation.

To better illustrate the impact of price sensitization-habituation, we set the baseline market-level propensity for category purchase to Φ_0= -0.75. As before, the optimal price and quality for the first generation is X*= 6 and P* = 6.3 resulting in a profit of $35 and a first generation penetration rate of 25%, a level that includes both innovators and early adopters Mahajan, Muller and Wind 2000).

One important simplification in our numerical analysis is the operationalization of the replacement rule. We assume that the current generation product need only have strictly higher levels of quality in order to be considered for purchase by consumers who already own a previous generation of the product.

4.3 Scenarios for Forward-Looking Firm

As noted above, the forward-looking firm must account for the dependencies that arise due to the replacement rule and the changes in price sensitivities due to past purchases. Thus the solution space grows exponentially with every generation. For example, consider the problem facing a firm optimizing over 8 generations. If the firm restricts itself to four discrete levels of price and three levels of quality, there are 12^8 = 429,981,696 possible paths to be evaluated. Therefore, we restricted our analysis to a five generation timeframe and the aforementioned 12 combinations of price and quality per generation. In this case we must compute the probabilities in Figure 1 a total of 12^5 times, one for each price-quality trajectory. One example of a price-quality trajectory is (X_1=4, X_2=4, X_3=6, X_4=6, X_5=6; P_1=4, P_2=4, P_3=4, P_4=4, P_5=9).

The price levels considered are {4, 6.3, 9, 11) and the quality levels were {4, 6, 8}. These levels include the first period solution for the myopic firm (P_1,Q_1) = (6.3,6) as well as higher and lower levels of both price and quality. We determined the optimal

absolute magnitude but not their qualitative nature. They are omitted to conserve space and are available from the authors.

price and quality levels for the forward-looking firm for a high (1/R = 0.7) and low (1/R = 0.95) discount rate. In order to conserve space, we focused our analysis on the situation in which price sensitization is followed by habituation after two purchases. Price sensitivity as a function of the number of purchases is illustrated in Figure 4.

5. Results

For each of the scenarios, we present the optimal levels of price, quality, value (quality/price), unit sales and profits (undiscounted) scaled with respect to the first generation (= 1.0). We also present the proportion of repeat purchases by generation.

5.1 Myopic Firm Scenario A: Decreasing Price Sensitivity (Sensitization)

When a consumer's price sensitivity is reduced with each purchase, the myopic firm's optimal strategy is to offer increased quality accompanied by even higher prices (see Figures 4A and 4B). These differences are more pronounced when the decrease in price sensitivity per purchase is larger (0.10 versus 0.05).

Figure 4 about here

The overall result of this strategy is a reduction in the value of firm's offering with each generation compared to the first generation product (see Figure 4C). This result is quite different from the results obtained by Kornish (2001) who assumed zero marginal costs and exogenously set quality. In her model, a firm either follows a low initial price strategy or focuses on customers with the highest valuation for the product. In the former case, the first period price is set low to attract as many buyers as possible. In the second period, the price of the greatly improved product is set higher in order to continued to be attractive to those consumers placing the greatest value on the product. The high valuation consumers are the focus in the first period when the firm employs the latter strategy. Here, the first period price is set high. Some low valuation customers buy in the second period (as do the high valuation customers) when the greatly improved replacement product in introduced at an increased, but very attractive price. While Kornish's (2001) analysis does not explicitly model the relationship between price and quality, it seems clear that, for both strategies, the firm increases the value for customers in the second period order to spur repeat purchases.

Our analysis suggests that if quality increases variable costs significantly (i.e. variable costs is a convex function of quality), then the myopic firm can increase profits by offering a higher quality product at much higher price. This is due to the influence of experience on price sensitivities. The consumer who has already purchased the product has lower price sensitivity than those who have yet to buy the product. Some of these experienced consumers are willing to repurchase in future periods to gain access to the higher levels of quality. Total sales, which consist of replacement sales along with sales to remaining potential first time buyers, generally increase over time (see Figure 4D). With each generation, the proportion of repeat sales increases (see Figure 4E).

One interesting result is the peaking of unit sales in later generations when the reductions in price sensitivity are larger (0.10 versus 0.05). Even though sales fall off after the eighth generation, overall profits continue to be high due to the number of experienced customers continuing to repurchase despite prices climbing much faster than quality.

5.2 Myopic Firm Scenario B: Increasing Price Sensitivity (Habituation)

In this scenario, when a customer purchases the product, his or her price sensitivity increases. In this case, the optimal strategy for the myopic firm is to keep quality fixed and slightly reduce the price over time[9]. The price reductions, overall, are small. This is a sharp contrast with scenario A (i.e. consumer price sensitivity declines with each purchase) wherein by the tenth generation prices had increased 70% and quality had increased almost 50%.

Figure 5 about here

With each generation, more consumers try the product. However, there are no repeat purchases and profits fall with each generation (see Figure 5).

While the myopic firm in this scenario is exhibiting classical skim pricing behavior, the underlying assumptions differ from the usual ones used in model those usually used to model durable pricing behavior. For example, the extant research assumes a heterogeneous distribution of consumers, some of whom would value buying the product more than others. In Coase (1972), these differences are operationalized as reservation prices. In addition, consumers are assumed to make only one purchase of the infinitely durable product. Quality is usually assumed to be fixed and the cost structure is

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[9] The results are essentially identical (within machine error) for the case of increasing price sensitivity by 0.05 and 0.10 per purchase. They are omitted to conserve space and are available from the authors.

one of low unit costs and high fixed costs. Our model relies on very different assumptions. Our consumers start out as being homogeneous, only changing as they purchase the product and become more price sensitive. A consumer would make replacement purchases if the quality were sufficiently high. Quality is endogenous and we assume that fixed costs are zero and unit costs are a quadratic function of quality. In the current literature on monopolists using price discrimination over time, the usual assumption is that the firm and consumers are forward looking. In this scenario, both consumers and the firm are myopic. Yet, the optimal strategy for the firm is the same, i.e. reduce prices over time as the market saturates. This suggests that skim pricing is an optimal strategy in a much wider range of situations than have been studied to date.

5.3 Myopic Firm Scenario C: Price Sensitization Followed by Habituation

In this scenario, price sensitivity varies according to the pattern identified in the sensitization-habituation literature (Wathieu 2004). During sensitization, a consumer's price sensitivity decreases with each purchase. However, after a number of purchases, the consumer becomes satisfied with the product last purchased and his or her price sensitivity increases. We modeled two situations, one in which habituation occurs after the third purchase and the other in which habituation occurs only after the sixth purchase (recall that in Scenario A, habituation did not occur regardless of the number of replacement purchases by the consumers). We determined the optimal price and quality for the myopic firm across the generations for the same baseline case used in the other scenarios.

We used a sensitization and habituation rate of 0.10 per purchase. Recall that changed the baseline market-level propensity for category purchase (β_0) to result in an initial trial rate of 25%. The results are presented in Figure 6.

Figure 6 about here

We see the impact of habituation in the leveling off of increases in price and quality (see Figures 6A and 6B). At this point, some of the first generation buyers will have made multiple replacement purchases and would have reached habituation. These consumers became <u>more</u> price sensitive, leading to a low likelihood of further purchasing. It is very interesting to note that after quality has reached its highest point, the firm starts to reduce prices to motivate more repeat and initial purchases. The value of the firm's offering is relatively higher when habituation sets in after fewer purchases (Figure 6C). In addition, unit sales fall off more swiftly when habituation sets in with fewer purchases (Figure 6D).

As might be expected from its dampening effect on price increases, habituation reduces the firm's profits. Profits are lower for the earlier onset case (3 purchases) since it takes fewer repurchases to get to the point that consumers leave the market (Figure 6F). When habituation is delayed until after the sixth purchase, the firm can continue to sell high quality and very high priced products to a narrowing group of repeat buyers and some new buyers. However, the increase in unit revenue cannot off-set the fall in unit sales and overall profits slump severely after the eighth generation.

These results suggest that if a firm is successful in attracting a large number of buyers in the first generation, it may eventually find itself providing higher quality than the market is willing to pay for. The onset of habituation results in a steep fall-off in profits after generations of successful product introductions and steeply growing profits. This overshooting of quality is well-known and has been dubbed as, "performance oversupply" by Christensen (1997).

Market leaders are rewarded with increasing profits over time by supplying their most demanding customers with additional performance and charging extra for it. These firms tend to assume consumers will be consistently interested in higher levels of performance, regardless of price (consistent with Scenario A). However, in industry after industry, Christensen (1997) finds firms tend to provide more performance than consumers need or are willing to pay for and eventually suffer the consequences of a steep drop-off in sales and profits. These results suggest that the onset of habituation can account for the phenomenon of performance oversupply.

In the next section, we examine how the time horizon (discount rate) of a forward-looking firm affects decisions regarding price and quality when price sensitization is followed by habituation after a small number of purchases. This analysis will help us better understand the role of the firm's time horizon on the incidence of performance oversupply.

5.4 Forward-Looking Firm Scenario D: Price Sensitization Followed by Habituation

For this scenario, we modeled two situations corresponding to a relatively high

(1/R = 0.7 per period) and relatively low (1/R = 0.95 per period) discount rate. The optimal price and quality levels of a forward-looking with a high discount rate start low and rapidly rise to their highest possible levels within three generations (Figure 7A and 7B). After that generation, the firm cuts its price while maintaining high quality. This echoes the pattern of the myopic firm discussed above (Scenario C). Like the myopic firm, the forward-looking firm with a high discount rate suffers from a steep fall off in profits (Figure 7F).

Figure 7 about here

In contrast, the forward-looking firm with a low discount rate builds its base of customers more gradually. This is indicated by the lack of repeat buyers in the second generation (Figure 7E). The value of its offerings is higher than that of the high discount rate firm until the last generation (Figure 7C). Overall, profits for the low discount rate firm are much higher in the last generation since there are so many more customers interested in trading up to the ultimate model (Figure 7F).

7. Discussion

In this paper, we develop a model to understand how changes in price sensitivity affect the firm's optimal price and quality as it introduces multiple generations of a durable good. Our model differs from the extant literature in two respects: replacement purchase motivation and the pattern of changes in price sensitivity. The consumers in our model are motivated to purchase a replacement product if the current generation offers better quality than the product most recently purchased (Rogers 1995). With respect to price sensitivities, we model the effects of price sensitization and habituation separately as well as together. These differences in the demand model provide valuable insight into durable good pricing in markets not characterized by the typical assumptions used in the extant literature. We summarize our findings in Table 1.

Table 1 about here

When price sensitivity decreases with each purchase (Scenario A), the optimal strategy for the firm is to offer a higher quality product at a much higher price. We actually observe this type of pricing behavior in markets where providing higher quality is very expensive. For example, consider the market for high performance cycling parts used in racing. In order to maximize his or her speed, a cyclist wants the lightest possible bicycle frame and components. At the same time, the materials used must be very strong in order to safely endure the strains of racing. These demands result in situations such as a 2.8 pound bicycle frame selling for $4100 at the same time that a frame weighting slightly more (3.1 ponds) costs only half as much (Pressman 2005).

In contrast to the recreational rock climbers studied by Youn, Song and MacLahan (2007), as competitive athletes progress in their sport, their price sensitivity often diminishes. That is, they are willing to pay increasingly high prices for only marginally higher quality. In bicycle case cited above, higher quality materials lead to reduced weight. Such behavior on the part of consumers may seem irrational, appearing similar to addiction. However, depending on the circumstances, the greatly increased price for a marginal gain in quality could be well justified. One clear example is equipment markets for sports such as golf, tennis, competitive fishing or racing. What these sports have in common is a tournament payoff structure. In other words, the payoff for finishing first (e.g., winning the U.S. Open, Indy 500 or Tour de France) is dramatically higher than the reward for those who finish second. At the highest levels of competition, athletes continually replace functioning equipment with new versions that have slightly higher performance and substantially higher prices. Under a tournament payoff structure, the additional expenditure contributing to even slightly improved performance may be rewarded.

When price sensitivity increases with each purchase (Scenario B), the optimal strategy is a skim pricing strategy. The firm sets a constant level of quality and reduces price over time as the market saturates. As noted above, this finding arises from a model that changes almost all of the assumptions regarding consumers (heterogeneity, forward looking v. myopic, single purchase v. replacement buying) and costs (nature of relationship between fixed and variable) that are used in the current literature.

Building on Wathieu (2004)'s exploration of how sensitization and habituation affects consumer purchasing, we illustrate its effects on the myopic (Scenario C) and forward-looking firm (Scenario D). We see that an earlier onset of habituation reduces the myopic firm's price, quality, sales and profits. Furthermore, the myopic firm or a prescient firm with a high discount rate will find itself providing higher quality than the market is willing to pay for. The onset of habituation results in a steep fall-off in profits after generations of successful product introductions and increasing profits.

Overshooting of quality in the market place was identified as, "performance oversupply" by Christensen (1997). Market leaders are rewarded with increasing profits over time by supplying their most demanding customers with additional performance and charging extra for it. These firms tend to assume consumers will be consistently interested in higher levels of performance, regardless of price (consistent with Scenario A). However, in industry after industry, Christensen (1997) finds firms tend to provide more performance than consumers need or are willing to pay for and eventually suffer the consequences of a steep drop-off in sales and profits.

Christensen's (1997) research is case based; it only provides a description of this phenomenon, not an explanation of why it occurs. Our analysis suggests that performance oversupply occurs due to the inflexion point between the sensitization and habituation processes. Consumers may continue to be interested in performance, but are not willing to pay for higher levels due to habituation. Since the product has a long life, consumers need not repurchase the latest generation even though it has higher quality. This leads to a steep drop off in sales and profits. Once habituation sets in, the only remaining course of action is to reduce prices to try to induce more repeat purchases.

It is interesting to note that forward looking firms with low discount rates follow a very different price/quality strategy. They build their customer base over multiple periods before greatly increasing the price and quality of the latest version. On a non-discounted basis, the profits from this strategy are much higher than those of the approach taken by a firm with a high discount rate. We often observe performance oversupply. Should we conclude that most managers are myopic or, at best, are forward looking but have very high discount rates?

While this question is outside the scope of this study, we speculate the managers may often follow a strategy that appears myopic or is inferior to one that is more forward looking, e.g. building up a customer base before greatly increasing price and quality levels. In our modeling framework, the firm is a monopolist and need not be concerned about competitive entry either by similar firms or ones with better (i.e. cheaper) technologies. It may be that firms consistently provide more quality at higher prices in order to maximize their discounted profits before the entry of new competitors or a major change in the production technology. Examining how competition interacts with consumer dynamics with respect to sensitization/habituation will be a challenging and interesting area for future research.

7.1 Limitations and Conclusions

As in Chintagunta and Rao (1996), we assumed consumers are homogeneous with respect to their change in preferences with each purchase. Future research might allow ownership (purchase) and consumption (usage) to vary separately. Also, we assumed homogeneous preferences at the beginning of the first period, a fixed market size and constant technology (as embodied in the cost structure). Relaxing these assumptions will provide very interesting avenues for future research.

In summary, we model how the influences of sensitization and habituation – first separately then together – affect the willingness of consumers to purchase replacement products in a durable good market. By incorporating these aspects of consumer heterogeneity into a model of consumer demand, we examine how the firm's decisions regarding price and quality change over successive generations. The findings of our numerical analyses provide insights into pricing behavior in understudied durable goods markets wherein replacement products must outperform those they replace.

Figure 1

Dynamics of Price Sensitivity (α_c):
Probability of Purchase as Function of Previous Consumption (c), and Product Generation (g).

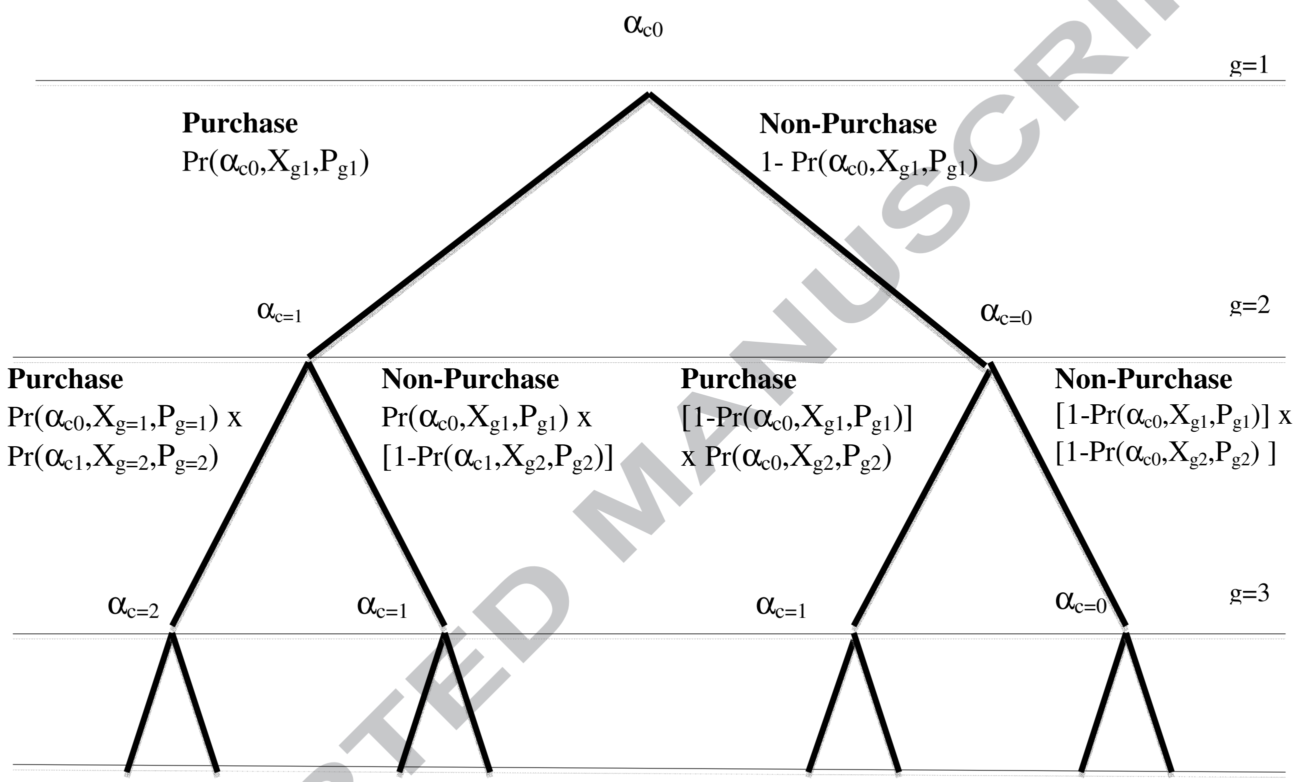


Figure 2: Example of Profit Function Discontinuity in Second Generation

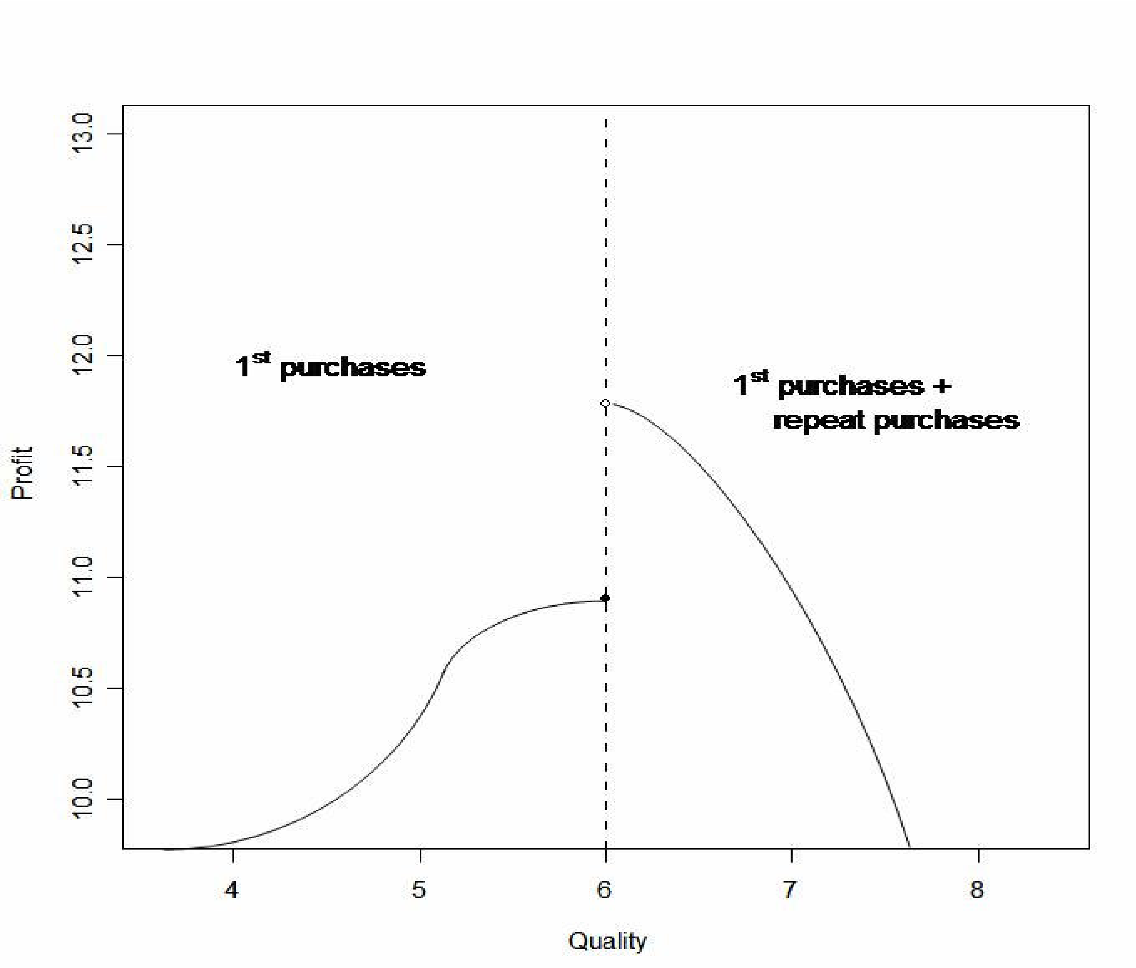


Figure 3: Changes in Price Sensitivity by Scenario

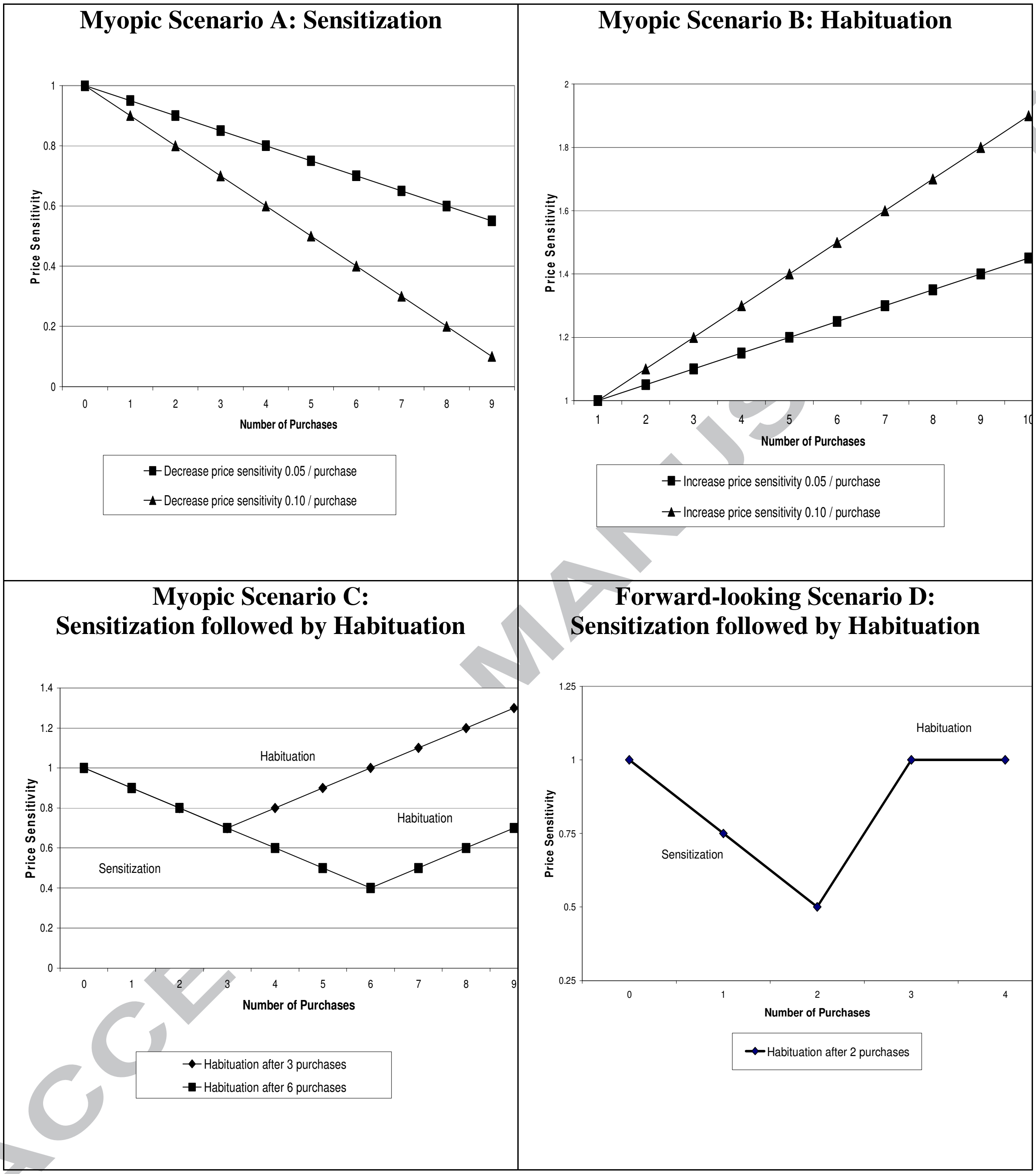


Figure 4

Results for Myopic Scenario A: Sensitization
(10% trial rate in 1st generation)

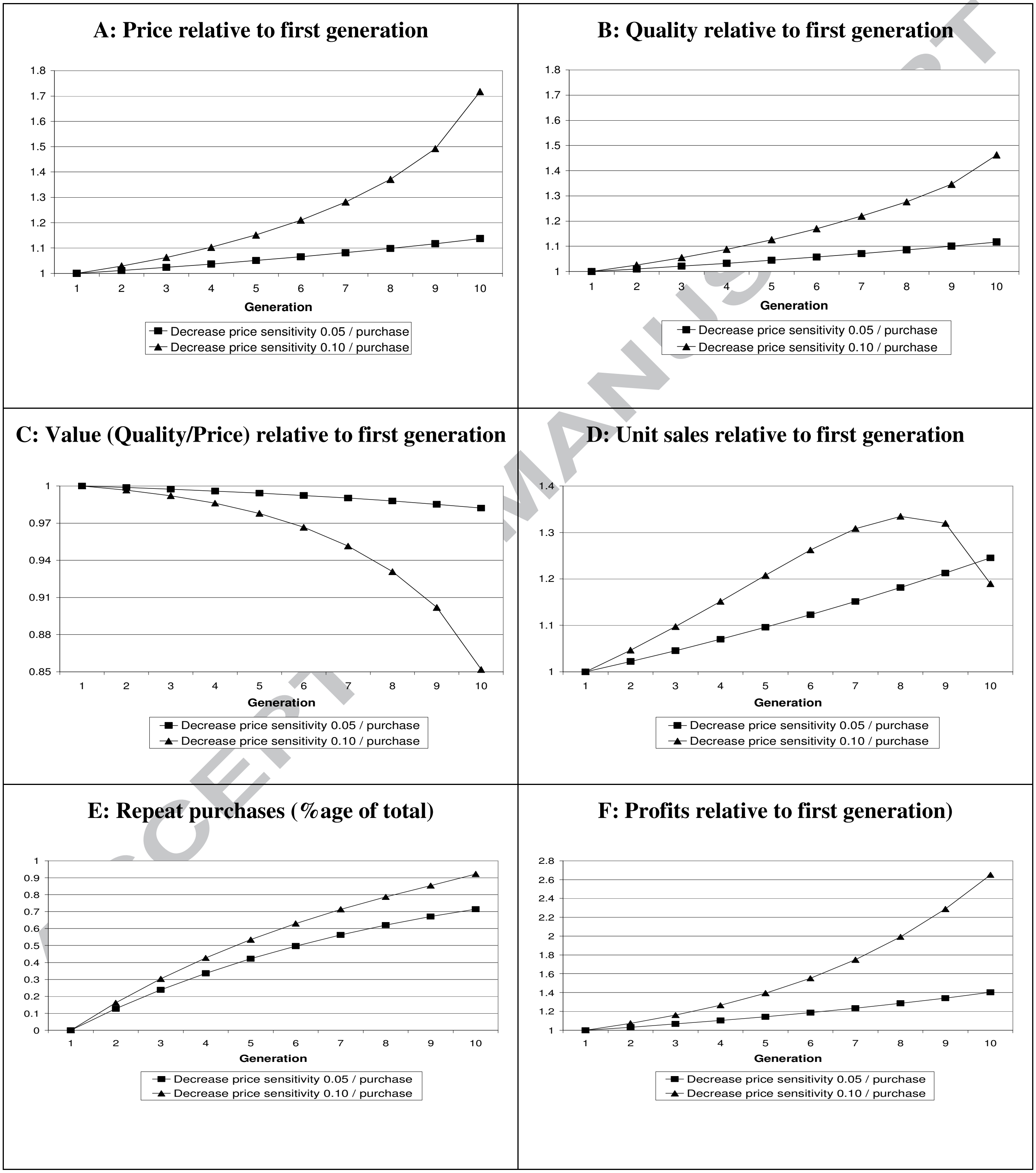


Figure 5

Results for Myopic Scenario B: Habituation (10% trial rate in 1st generation)

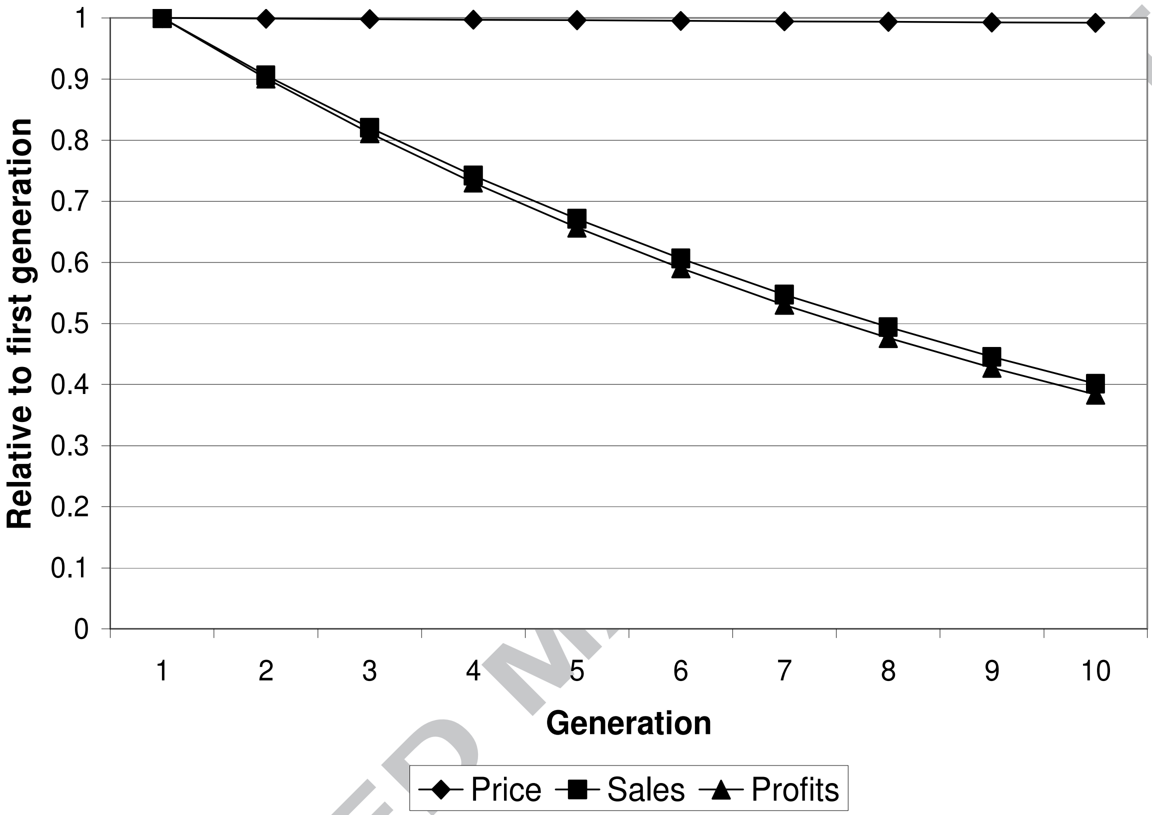


Figure 6

Myopic Scenario C: Sensitization followed by Habituation (25% trial rate in 1st generation)

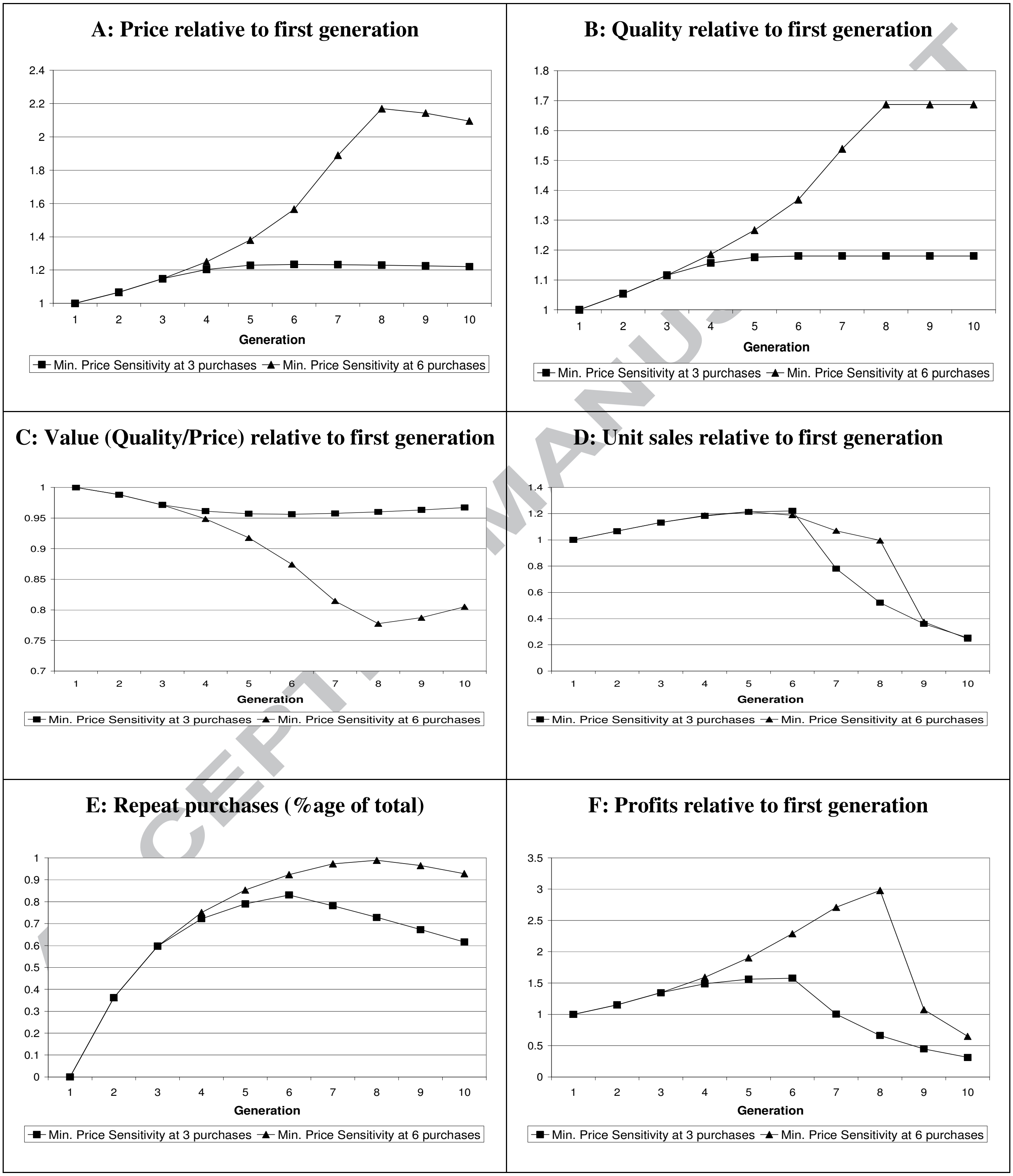
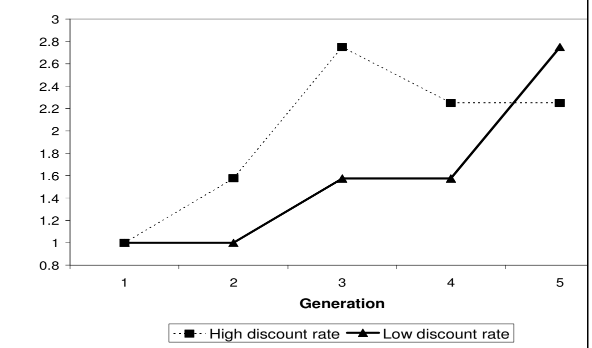


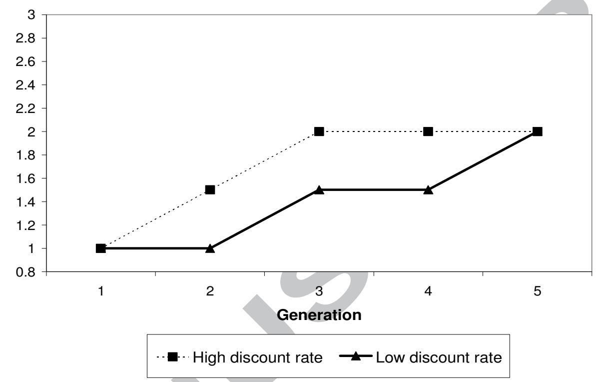
Figure 7

Forward-Looking Scenario D: Sensitization followed by Habituation (10% trial rate in 1st generation)

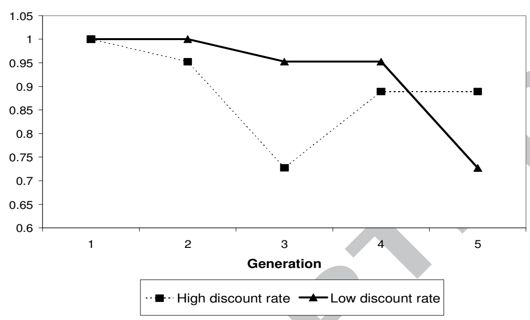
A: Price relative to first generation



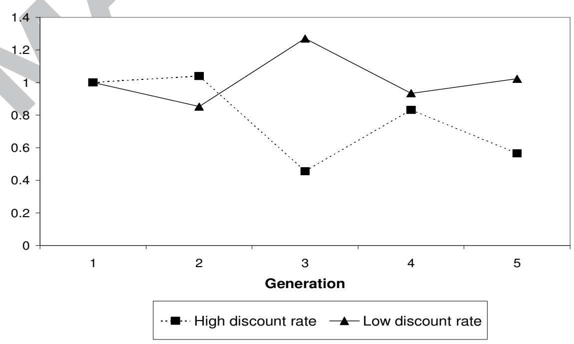
B: Quality relative to first generation



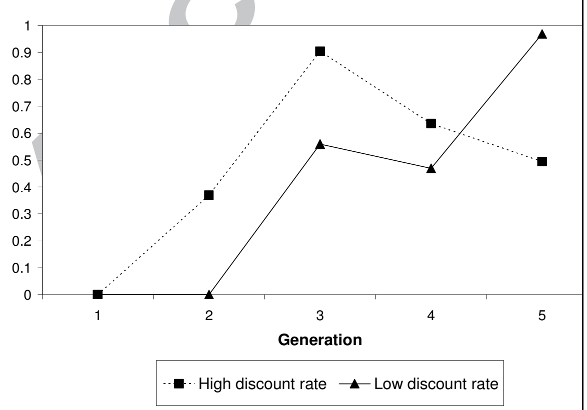
C: Value (Quality/Price) relative to first generation



D: Unit sales relative to first generation



E: Repeat purchases (%age of total)



F: Profits relative to first generation (undiscounted)

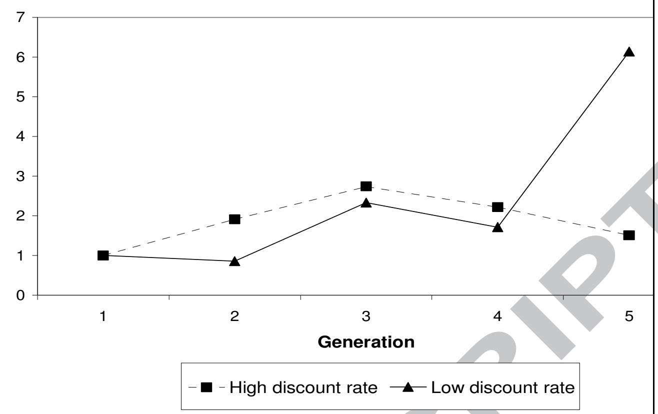

7
6
5
4
3
2
1
0
1
2
3
4
5
Generation
High discount rate
Low discount rate

Table 1

Summary of Results

Scenario	**Major Findings**	**Related Citations**
A: Sensitization = Decreasing Price Sensitivity (myopic firm)	**"Addicted" to Performance** • Prices rise much faster than quality • Value falls with each generation • Proportion of repeat buyers increases with every generation • Sales may fall as market saturates • May be relevant when there is a tournament payoff to performance gains	Becker and Murphy (1988)
B: Habituation = Increasing Price Sensitivity (myopic firm)	**Coasian Saturation** • Price and profits fall over time • No repeat purchases • Same limit pricing outcome from very different initial assumptions	Coase (1972)
C: Sensitization Followed by Habituation (myopic firm)	**Performance Oversupply** • Rapid increase in price and quality until habituation sets in • Very high peak in profits followed by sharp fall-off	Wathieu (2004) Christensen (1997)
D: Sensitization Followed by Habituation (forward-looking firm)	**Discount Rate Determines Strategy** • Low = builds customer base over multiple generations • High = performance oversupply	Wathieu (2004) Christensen (1997)

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