

# TECHNOLOGY TIMING AND PRICING IN THE PRESENCE OF AN INSTALLED BASE

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# TECHNOLOGY TIMING AND PRICING IN THE PRESENCE OF AN INSTALLED BASE

## Abstract

This paper studies a vendor's timing and pricing strategies to tackle its own installed base when selling a newly improved product. We characterize the market with either a partly- or fully- covered installed base, consumers' relative willingness to pay for the newly improved version of the product, and their relative payoffs from delayed purchase. Instead of using the conventional assumption of constant consumer reservation price, we propose that if consumers already own an existing (old) version of a durable product, their willingness to purchase the newly improved version would increase over time. This effect, interweaving with consumer heterogeneity on valuation of quality and purchase history, may enable perfect intertemporal price discrimination (Salant 1989). We find that upgrade pricing may not be able to differentiate consumers with different purchase history when consumer heterogeneity is sufficiently high. Instead, the vendor would maximize its profit through intertemporal price discrimination, delayed product introduction, or pooling pricing. By overcoming the intractability of studying delayed product introduction in a market with heterogeneous consumers, this study analytically confirms Fishman and Rob's conjecture (2000) that heterogeneity in consumers' valuation of quality may discourage a vendor to launch a new product. Particularly, consumers' anticipation of future price reduction can lead to delayed product introduction even when the extent of quality improvement embodied in the new product is high.

## Key Words

*Installed base, Upgrade, Intertemporal price discrimination, Delayed product introduction*

## **1 Introduction**

Firms in the information technology (IT) industry face a paradox of rapid technological progress. To sustain ongoing industry leadership, a firm should strive to develop the next best technology (Mohr, Sengupta and Slater 2005). However, the firm's newly improved technology may render obsolete its old technology, which could cause competitive volatility. Further, the installed base of its own product that uses the old technology could turn to be a formidable competitor of the new technology, particularly when technological progress outpaces users' capacity of fully utilizing the old technology (Varian 2004). Although both hardware and software vendors earn significant revenue by selling users newer versions of what the users already have, many users are increasingly resisting the purchase of upgrades solely for the sake of upgrading (Richter 1995). Because of the accumulation of past purchases and the durable nature of many information goods, the number of existing installed units can be an order of magnitude greater than the number sold annually (Wise and Baumgartner 1999). Examples include third-generation cellular phone facilities and services vis-à-vis a large number of existing users who are using second-generation cellular networks and handsets, and DVD video recorders vis-à-vis the installed base of conventional videotape recorders. In the personal computer (PC) and mainframe computer industry, a major concern for vendors is to tackle the reluctance of customers to replace old PCs or mainframes by newer ones (McDonald 2006). Even for computer software, with more than 90% of PCs running some sort of Windows, Microsoft has long considered its main competitor to be the installed base of its own products (Berlind 2005).

Being aware of balking consumers caused by rapid technology improvement (Dhebar 1996), prior research in new product introduction suggests that to entice users to upgrade their old products, vendors have the incentive to reduce product durability (Bulow 1986, Waldman 1996a). If a vendor is unable to artificially shorten its product durability, it may offer upgrade price discounts to existing users, which is also socially optimal (Waldman 1997, Fishman and Rob 2000).

In information goods industries, new business models are replacing the traditional shipment-based sales model in order to reduce product durability, thus eliminate the negative effect of installed base (Rappa 2006). Information goods comprise mainly of digital "signals". Given the lack of

physical constraints on production and operation, and being facilitated by the Internet, some software vendors have managed to control durability by licensing their software or providing periodic services (see, e.g., Microsoft's software subscription model, Graphsoft's 'pay per use', and the more recent "software as a service" (SaaS) model adopted by SalesForce.com). Even hardware vendors have gone downstream along the supply chain towards providing services required to operate and maintain their products<sup>1</sup>. These business models aim at generating perpetual revenues by transforming durable products into subscription-based services – a form of 'leasing'.

Nevertheless, transforming business model may not solve the conflict between the existing installed base and new products. Users' complaints about 'forced upgrades' have never ceased. By paying a recurring fee in exchange for an always up-to-date application, users are likely to spend more in the long run (Bulow 1982, Kandra 2006). Further, many software vendors are unwilling to provide free upgrades even if users have subscribed to renewable annual services<sup>2</sup>, and, opposite to the advocates of SaaS, IT consultants have pointed out that SaaS applies best to applications that can be run in isolation, but not for mission critical applications or when there is data exchange between the service providers and clients (Ferravanti 2004, James 2006). As for hardware-vendors' downstream movement mentioned above, it makes sense only for some particular combination of market structure and product characteristics<sup>3</sup> (Wise and Baumgartner 1999).

Compared to the analysis of reducing durability, studies on timing and pricing strategies to cope with installed base of old products are lacking. Most of the existing research on product line introduction employs a two-period framework, which assumes a fixed introduction time for the new product (launching in the second period or not launching) (see, e.g., Fudenberg and Tirole 1998). This restricted setting constrains vendor's flexibility in selling the new product in view of a considerable installed base of its older product -- the vendor can induce consumers' self-selection of whether or not

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<sup>1</sup> Successful examples include IBM global service, Nokia's integrated solution, and Dell's hybrid manufacturing and direct distribution model (Wise and Baumgartner 1999).

<sup>2</sup> PC World magazine reported the upgrade confusion and pressure to upgrade from users of Symantec's Norton Antivirus, Intuit's Quicken, Microsoft's Money, Corel's Jasc Photo Album, Mathsoft's Math CAD, etc. See <http://www.pcworld.com/howto/article/0,aid,123396,00.asp>.

<sup>3</sup> Wise and Baumgartner (1999) provide a matrix to characterize downstream opportunities. For instance, a downstream move in the VCR market is not attractive considering its low installed-base-to-new-unit ratio and the trivial costs associated with VCR ownership and usage.

to purchase the new product in the second period, *but not when to purchase it*. This is unrealistic since introduction timing has long been recognized as an important instrument to differentiate consumer segments (Moorthy and Png 1992). Recurrent model or continuous-time models have also been applied in studying technology innovation and product introduction. However, to make the models tractable, the researchers have either assumed that consumers are homogeneous in valuing product quality (Fishman and Rob 2000), or studied the introduction of only a single product (Stokey 1979).

Generally, the following are limitations of some of the prior studies in this area:

- First, they mostly focus on static analysis of demand in a market consisting of consumers who differ in their valuation of product quality and purchase history (Lee and Lee 1998). Little research has addressed the same issue incorporating the time dimension. The complexity of consumer demand lies not only in the heterogeneity among consumers, but also the market as a carrier of history and the future. It is important to take the time dimension into consideration when studying consumer choices and the vendor's product introduction strategies.
- Second, previous studies have not considered upgrade pricing in view of the time dimension. In particular, we would like to ask in this study how should a vendor respond to demand variation by leveraging intertemporal or intra-temporal price discrimination.
- Third, it has long been considered that with upgrade pricing, vendors will adopt socially efficient strategies (Waldman 1997, Lee and Lee 1998, Fishman and Rob 2000). In this study, with a more general setting that encompasses consumer's heterogeneity in valuation of product quality (cf. the high heterogeneity setting in Lee and Lee (1998) and the homogeneous setting in Fishman and Rob (2000)), are there situations in which upgrade pricing loses its power to segment the market? If so, can a vendor sustain its monopoly power using time as a differentiation instrument?

This study addresses the above questions, and investigates alternative strategies other than merely changing durability, which has been ably studied in past research (Bulow 1986, Waldman 1996a). Specifically, we investigate the optimal combinations of timing, pricing and product line strategies that the vendor can employ to sell its newly improved product in the presence of an existing installed base. Two cases, a fully-covered installed base and a partly-covered installed base, are

studied in a two-period framework with consumers differing in their valuation of product quality and/or purchase history, and with a monopolist vendor selling sequential versions of its products with exogenous durability and quality, and zero variable production costs. In the full ranges of the extent of product quality improvement and the extent of consumer heterogeneity on valuation of quality, we characterize consumers' relative willingness to pay for the newly improved version and their relative payoffs from delayed purchase. Our contributions are as follow:

First, instead of making the conventional assumption of constant consumer reservation price, we propose that if users have already owned an existing (old) version of a durable product, their willingness to purchase the new version would increase over time. This effect, when interweaving with consumer heterogeneity on valuation of quality and purchase history, could enable perfect intertemporal price discrimination by which low valuation users who have not yet purchased any product will purchase the new version earlier than high valuation users who own the previous version. Further, the high valuation users' incentive to postpone purchase may actually make them worse off, which is contrary to popular findings in the price discrimination literature (see, e.g., Moorthy 1984, Moorthy and Png 1992).

Second, we find that the vendor may delay the introduction of the new version because of the combined dampening effect of the existing installed base and users' anticipation of future price reductions. The equilibria of such delayed introduction exist regardless of the extent of user heterogeneity on valuation of quality and the extent of quality improvement between the sequential versions of products.

Third, by studying a more general setting, we find that upgrade pricing may not differentiate users with differing purchase history if user heterogeneity is sufficiently high. In this case, depending on market structure and the extent of technology improvement, instead of upgrade pricing, the vendor could maximize its profit through intertemporal price discrimination, delayed production introduction, or pooling pricing.

Finally, we suggest that without considering marginal cost of production (which is common in this literature), social welfare directly depends on whether the vendor can sustain its monopoly

power in view of the mutual cannibalization between the old and new products and the mutual arbitrage between heterogeneous users.

The remainder of this paper is organized as follows. Section 2 reviews the related literature. Section 3 presents our research model. Section 4 outlines the analysis and characterizes the equilibria in both the fully-covered installed base and partly-covered installed base cases. Finally, Section 5 concludes the study.

## **2 Prior Literature**

This research is grounded on the extensive literature of durable goods monopoly, and is related to two streams of works in economics and marketing. One stream of research is about market segmentation and price discrimination (see, e.g., Mussa and Rosen 1978, Stokey 1979, and Moorthy 1984); the other is about planned obsolescence (see, e.g., Coase 1972). The former stream studies the vendor's strategic choice of timing and quality allocation to extract the surplus of users with heterogeneous valuation of product quality (Moorthy and Png 1992, Padmanabhan, et.al. 1997). The latter stream studies its incentive to eliminate the stock of the old durable good and the welfare effects of physical obsolescence (induced by durability reduction) (Bulow 1982, 1986, Waldman 1996a) and economic obsolescence (induced by new product introduction) (Waldman 1993, 1996b, Lee and Lee 1998, Fishman, Gandal and Shy 1993, Fishman and Rob 2000). Despite different focuses, these two streams of research studied agents with the common characteristics: rational consumers and a durable-goods monopolist seeking to sustain its monopoly power.

The literature on new product introduction uses a conventional assumption that all users possess nothing at the beginning of the game (Kornish 2001). Our study relaxes this assumption and generalizes the consumer utility function by considering various scenarios pertaining to their possession of a low-quality product at the beginning of the game. This captures the variation of

consumer utility as a function of purchase history and time, and at the same time simplifies a multi-stage game into a two-period game<sup>4</sup>.

The research on market segmentation and price discrimination has shown that if the monopolist is unable to identify users with heterogeneous valuation of quality, it may induce users' self-selection by simultaneously offering a menu of qualities (Mussa and Rosen 1978), i.e., static price discrimination, or a sequence of prices for the same product over time (Stokey 1979), i.e., intertemporal price discrimination. In the context where the monopolist is able to commit its price and quality, Salant (1989) addresses the optimality of inducing users' self-selection by synthesizing the works conducted by Stokey (1979), Mussa and Rosen (1978) and Spence (1977, 1980). He proposes that inducing self-selection is suboptimal with linear costs but may be advantageous when users have linear valuations of quality, and when marginal costs are convex in quality. As for static price discrimination, Moorthy (1984) proves that users with the highest valuation of quality get the socially efficient product quality, but lower valuation users would be inefficiently served. Moorthy and Png (1992) examine the interaction of quality discrimination and intertemporal price discrimination in a two-period model when the new technology is available at the beginning of the game. They find that employing both time and quality as instruments to extract users' surplus (sequentially selling two products to the high and low valuation users) is optimal only if cannibalization is a problem and users are relatively more impatient than the vendor. Further, they show that when pre-commitment is infeasible, sequential selling is less attractive compared to the case with commitment because the vendor's private incentive of maximizing profits in the second period makes itself worse off in the first period (i.e., the vendor faces a time inconsistency problem).

In the above studies, technology innovation is not the main concern. Thus, once any consumer has purchased one unit of the product, she will leave the market (Moorthy and Png 1992). This is similar to the first case studied in this paper – a fully-covered installed base, where users in the market only differ in their valuation of quality but not their purchase history. The difference is that we

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<sup>4</sup> It is complicated to study games with more than two periods in a market with heterogeneous consumers because of the exponential increase in the number of combinations of timing, pricing and product line strategies. Hence, prior research with multi-period models typically simplify their setting to a market with homogeneous consumers (e.g., Fishman and Rob 2000, Ruiz 2003)

assume all users hold the low-quality product at the beginning of the game. In Section 4.1 we investigate how this more general setting affects the optimality of intertemporal price discrimination and compare our findings to the previous studies.

Prior research considers users' repeat purchase when technology improvement renders the existing technology obsolete. A general setting that has been widely applied is a two-period model in which the vendor can only sell the low-quality (old) product in the first period; at the beginning of the second period, due to technology innovation, the vendor can produce and sell the high-quality (new) product.

The studies on market segmentation and price discrimination are interested in vendor's strategies to tackle the demand-side constraints imposed by repeat purchase. Dhebar (1994) finds that if users expect the product to improve in present value terms and the monopolist cannot credibly commit to future prices and quality, intertemporal price discrimination may result in disequilibrium regardless of whether upgrade pricing is offered or not. Subsequently, in a similar setting, Kornish (2001) extends Dhebar's work and finds that a sub-game perfect equilibrium exists if quality improvement is exogenous and upgrade pricing is not offered. Both Dhebar's and Kornish's work imply that the vendor may be better off if it can delay the introduction of the new product in some situations, but they did not explicitly study this phenomenon and characterize the equilibria. Fudenberg and Tirole (1998) incorporate market information as another input variable and analyze the situations in which upgrade or buy-back is profitable.

Studies on planned obsolescence concern more about the vendor's incentive to introduce a new product which leads to the economic obsolescence of the old product. Levinthal and Purohit (1989) measure the extent to which the old product is rendered obsolete by the extent of quality improvement and the degree of substitutability. Lee and Lee (1998) explicitly incorporate price discrimination based on purchase history and valuation of quality. They propose that price discrimination based on purchase history<sup>5</sup> serves for the vendor to internalize the loss from economic obsolescence, thus eliminates the time inconsistency problem induced by new product introduction

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<sup>5</sup> This is equivalent to upgrade pricing whereby only the old users are offered a discounted price for upgrading to the new product.

(although the time inconsistency problem induced by selling to low valuation users in the subsequent period may still exist.).

Examining the findings of Dhebar (1994), Kornish (2001) and Lee and Lee (1998), we find that the setting of the fixed introduction timing for the new product (launching in the second period or not launching) constrains the monopolist's choice of selling the new product: it can induce users' self-selection of *whether or not* to purchase the new product in the second period, but not *when* to purchase. This is unrealistic considering the fact that vendors often use timing to segment the market. Different from Moorthy and Png's setting (1992), in this study the potential market for the new product consists of not only new users but also the existing users who have owned the old product. Our second case (partly-covered installed base) bridges the gap between the practice and the literature in a tractable setting. Specifically, we examine the profitability of various combinations of timing and pricing strategies for selling the new product in the presence of existing stock of the old product<sup>6</sup>.

This study particularly contributes to the understanding of vendor's incentive to delay the introduction of a new product. Fishman and Rob (2000) suggest that in an infinite-time framework with homogeneous users, no upgrade policies, and perfectly durable products, a monopolist's rate of product innovation would be too low, which can cause inefficient delays in new product introduction. They show that with an upgrade policy, however, the vendor would not delay new product introduction. This study extends their work into a heterogeneous market and derives various product introduction strategies that are applicable in practice.

### 3 Basic Setting

Consider a model with three periods,  $t$ ,  $t \in \{0, 1, 2\}$ . There exists a monopolist vendor who is planning to sell two versions of a durable product, indexed by  $x$ ,  $x \in \{O, N\}$ . Up to period 0, it can only sell a low-quality product,  $O$ , with quality  $q_O$ . Owing to R&D, a new technology arrives in period 1, which allows the vendor to produce and sell a new product,  $N$ , with quality  $q_N > q_O$ , in either period 1 or 2.

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<sup>6</sup> Ruiz (2003) investigates timing and pricing strategies of new product introduction in a three-period model but only with homogeneous users.

For ease of presentation, we normalize  $q_N$  to one, and so  $0 < q_O < q_N = 1$ .  $q_O$  measures the extent of quality improvement embodied in the new product. A smaller  $q_O$  represents a higher extent of quality improvement. Both the old (low-quality) and new (high-quality) products are of the same durability of  $n$  ( $n \geq 2$ ) periods<sup>7</sup>.  $n$  can be considered as the relative lifespan of a product compared to the time window of product introduction and technology improvement. The assumption that  $n \geq 2$  is to capture the characteristics of IT-intensive products which typically have a shorter economic lifespan than physical lifespan (Fishman and Rob 2000). We further assume zero fixed and marginal costs to focus on the strategic choices of the vendor in response to demand variation.

On the demand side, there are two types of consumers (the high type and the low type), indexed by  $e \in \{H, L\}$  and having sizes  $d_H$  and  $d_L$ , who differ in their valuation of product quality,  $v_H > v_L$ . Each type  $e$  consumer values a product with quality  $q_x$  and durability  $n$  at  $v_e q_x \frac{1 - \delta^n}{1 - \delta}$  which is the discounted sum (over  $n$  periods) of the periodic service value provided to the consumer by product  $x$ . We normalize  $d_H + d_L = 1$ . Let  $v_L^H = v_H / v_L$ , which measures the heterogeneity of consumers in terms of valuation of quality; larger  $v_L^H$  implies a higher consumer heterogeneity. Each consumer demands at most one unit of either version of the product. Within its life span, the product provides a constant stream of service to consumers: once consumers buy it, they enjoy a value that equals its quality in each period of service until it is retired (either because it is replaced by a newer product, or because it has exceeded its physical life span). There is no second-hand market; hence, as soon as consumers buy a new product, their old products are retired and provide zero usage or residual values. We use  $\delta$  ( $0 \leq \delta \leq 1$ ) to denote a discount factor, which is common to both the vendor and consumers. The larger  $\delta$  is, the smaller the discount in future utilities or prices will be. Following Taylor (2002), we use  $d_H v_L^H$  as a measurement of demand elasticity. Larger  $d_H v_L^H$  means that the demand is less elastic.

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<sup>7</sup> When  $n$  goes to infinity, the product is perfectly durable, which is the case studied in Fudenberg and Tirole (1998) and Kornish (2001).

In period 0, some consumers may purchase the old product, which results in an installed base at the beginning of period 1. We study two cases. In the first case (named a fully-covered installed base), both types of consumers have purchased the old product in period 0. In the second case (named a partly-covered installed base), only the high type have purchased the old product in period 0. We are not interested in the case of no purchase in period 0, since it degenerates into a two-period model similar to that studied in Moorthy and Png (1992)<sup>8</sup>.

Periods 1 and 2 further consist of two stages. In the first stage, the vendor makes product and pricing decisions based on its knowledge of consumer profiles (how many people bought the products in the previous periods, the utilities they derive from the products, etc.). In the second stage, consumers make purchase decisions, taking into account their valuations of the products and expectations about future products. There is common knowledge on demand, product quality, and technological improvement. Perfect information on history of moves by the vendor and consumers is available. We focus on rational expectations equilibria in which consumers form expectations about the product and pricing decisions of the vendor, and the vendor fulfills such expectations.

In the case of a partly-covered installed base, we separate the analysis into two scenarios. In the first scenario, the vendor cannot provide an upgrade option to consumers; hence, all consumers pay the same price for the new product. In the second scenario, the vendor can use an upgrade policy, which allows consumers to trade in the old product for the new product at a discounted price. The price of product  $x$  in period  $t$ ,  $t = 1, 2$  is denoted by  $p_t^x$ ; the upgrade price of the new product in period  $t$  is denoted as  $p_t^{Nu}$ . In the fully-covered installed base case,  $p_t^N = p_t^{Nu}$ , since both types of consumers possess the old product and thus share the same purchase history. For the convenience of the subsequent analysis, we denote:

$$q_1 = [1 - 2\delta][1 - \delta^n] / [1 - 2\delta + \delta^{n-1}], \quad q_2 = 1 - \delta^n, \quad \text{and } q_1 < q_2 \text{ in the range of } q_1, q_2 \in [0, 1].$$

$$v_1 = [1 - \delta^n] / \{1 - \delta^n - [1 - \delta^{n-2}]q_o\}, \quad v_2 = [1 - \delta^n] / \{1 - \delta^n - [1 - \delta^{n-1}]q_o\},$$

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<sup>8</sup> We do not study the vendor's strategy in period 0 as we want to focus on how to launch the new product in view of an existing installed base of old product. Endogenizing period 0 strategies will substantially complicate the analysis and solution space, and hence we leave it as a challenge for future research.

$$v_3 = [1 - \delta^n] / [1 - \delta^n - q_o], \text{ and } v_1 < v_2 < v_3.$$

## 4 Analysis

If consumers do not possess any product before their purchase, they can derive the full utility that the product provides in its lifespan. Equation (1) below represents the *willingness* of a type- $e$  consumer,  $e \in \{H, L\}$ , to purchase product  $x$ ,  $x \in \{O, N\}$ , in period  $t$ ,  $t = 1, 2$ :

$$z_{xt}^e = v_e q_x [1 - \delta^n] / [1 - \delta]. \quad (1)$$

The corresponding (discounted) utility in the present value terms of period 1 is

$$Z_{xt}^e = \delta^{t-1} z_{xt}^e. \quad (2)$$

Alternatively, suppose a consumer has purchased the old product in period 0. Then she only values the *incremental* utility provided by the new product. Equation (3) represents this consumer's *willingness* to purchase the new product  $N$  in period  $t$ ,  $t = 1, 2$ .

$$u_{Nt}^e = v_e [1 - \delta^n] / [1 - \delta] - q_o v_e [1 - \delta^{n-t}] / [1 - \delta] \quad (3)$$

Her corresponding utility in the present value terms of period 1 is:

$$U_{Nt}^e = \delta^{t-1} u_{Nt}^e. \quad (4)$$

The first term on the right hand side of equation (3) is the full usage value that the consumer can derive from the new product if she does not possess the old product. The second term is the remaining usage value of the old product given that it has been consumed for  $t$  periods. Equations (1) and (3) are equivalent, i.e.,  $u_{Nt}^e = z_{Nt}^e$ , if the old product does not exist, i.e.,  $q_o = 0$ . The same applies to equations (2) and (4). Note that if the consumer does not own any product, her willingness to purchase remains constant, i.e.,  $z_{x1}^e = z_{x2}^e$ , while she gains higher utility from an earlier purchase,  $Z_{x1}^e > Z_{x2}^e$ . However, if the consumer bought the old product in period 0, her willingness to purchase *increases* over time, i.e.,  $u_{N1}^e < u_{N2}^e$ , because depreciation of the old product raises the incremental benefit that she can derive from the new product. Further, the consumer enjoys higher utility from earlier purchase of the new product,  $U_{N1}^e > U_{N2}^e$ , if and only if the extent of quality improvement is sufficiently high,

$q_0 \leq q_2$ . Otherwise, if  $q_0 > q_2$ , her utility derived from the new product actually increases over time,  $U_{N1}^e < U_{N2}^e$ .

Considering the changes of equations (2) and (4) with respect to  $t$ :

$$\frac{\Delta Z_{xt}^e}{\Delta t} = \frac{Z_{x[t+\Delta t]}^e - Z_{xt}^e}{\Delta t} = \frac{\delta^{\Delta t} - 1}{\Delta t} \frac{\delta^{t-1} [1 - \delta^n]}{1 - \delta} v_e q_x \quad (5)$$

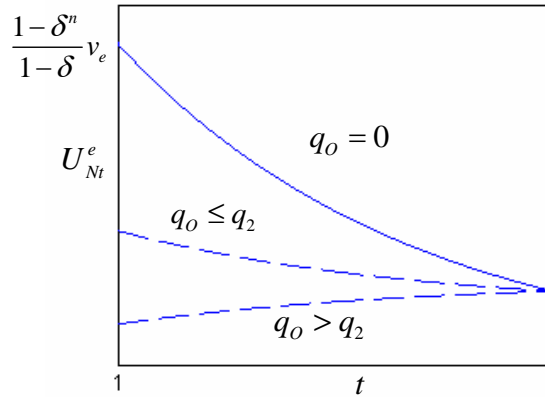
$$\frac{\Delta U_{Nt}^e}{\Delta t} = \frac{U_{N[t+\Delta t]}^e - U_{Nt}^e}{\Delta t} = \frac{\delta^{\Delta t} - 1}{\Delta t} \frac{\delta^{t-1} [1 - \delta^n - q_0]}{1 - \delta} v_e \quad (6)$$

where  $\Delta t = 1$ . We consider  $\Delta Z_{Nt}^e / \Delta t$  and  $\Delta U_{Nt}^e / \Delta t$  as the marginal utility of waiting if type  $e$  consumers delay their purchase of the new product for one period. If  $q_0 \leq q_2$ ,  $\Delta Z_{Nt}^e / \Delta t < \Delta U_{Nt}^e / \Delta t \leq 0$ ; if  $q_0 > q_2$ ,  $\Delta Z_{Nt}^e / \Delta t < 0 < \Delta U_{Nt}^e / \Delta t$ . Further, for consumer having purchased the old product, the marginal utility of waiting increases with  $q_0$ , i.e.,  $\Delta^2 U_{Nt}^e / \Delta t \Delta q_0 > 0$ .

Proposition 1 summarizes the above findings:

**Proposition 1.** If a consumer has purchased the old product, because of depreciation: (1) her willingness to purchase the new product *increases* over time; (2) she is better off from delaying the purchase of the new product if and only if  $q_0 > q_2$ . Otherwise, if  $q_0 \leq q_2$ , she is worse off by delaying the purchase of the new product, but her loss from delaying the purchase is smaller compared with the case of not possessing the old product in period 0. (3) The marginal utility of delayed purchase of the new product increases with  $q_0$ .

We compare the utility that a consumer can derive from the new product ( $U_{Nt}^e$ ) in three situations and illustrate their time trends in Figure 1: (1) no purchase before the game ( $q_0 = 0$ , and thus  $U_{Nt}^e = Z_{Nt}^e$ ); (2) purchasing the old product with quality  $q_0 > q_2$  in period 0; (3) purchasing the old product with quality  $q_0 \leq q_2$  in period 0.



**Figure 1. Consumer's Utility from Upgrading to the New Product**

Proposition 1 states our key disposition which is different from prior research. The literature of new product introduction holds a conventional assumption that all consumers possess nothing at the beginning of the game (i.e.,  $q_o = 0$ ) (Kornish 2001). Consequently, a consumer's willingness to purchase the new product remains constant and her utility derived from the new product decreases over time (i.e., she is always "impatient"). Here, we assume that consumers possess the old product and have already consumed it for one period before the game begins. Thus, the old product in hand depreciates over time which increases their need for upgrade. If the quality difference between the old and new products is sufficiently low (i.e.,  $q_o \geq q_2$ ), the depreciation of the old product would increase the value of the new product to consumers over time. This could outweigh the loss in utility from delaying the consumption of the new product. Hence, the (discounted) net utility that consumer derives from the new product *increases* over time as shown in Figure 1.

Proposition 1 has important implications for product introduction strategy. One of the main concerns in second-degree price discrimination is the conditions under which a firm can maximize profit by inducing self-selection in quality, quantity or purchase timing (Mussa and Rosen 1978, Spence 1980, Stokey 1979, Salant 1989). By Proposition 1, having possessed the old product, a consumer's marginal utility from delayed purchase of the new product is less negative (or in some cases even positive) compared to the case of not possessing the old product. Consequently, earlier purchase is less attractive to consumers who have owned the previous version. Compared to the findings with no installed base (Moorthy and Png 1992), we expect that the conditions favoring intertemporal price discrimination on selling the new product would become more stringent in the

presence of a fully or partly covered installed base. However, our subsequent analysis shows that this is true only in some situations.

#### **4.1 A Fully-Covered Installed Base**

In this case, both the high and low types bought the old product in period 0 and thus share the same purchase history. The technology to produce the new product is available at the beginning of period 1. The vendor has to solve an old problem that has been extensively studied in the literature of new product introduction (Salant 1989): when and how should it induce self-selection for selling the new product? The interesting point in this context is that consumers' willingness to purchase the new product is not constant but rather increases over time, and their discounted incremental utility from upgrading to the new product is subject to changes as we outlined in Proposition 1. The conventional setting of the absence of an installed base can be obtained in the extreme case of a fully-covered installed base with  $q_0 = 0$ .

The vendor's product introduction schedule consists of its decision on timing, pricing and product line strategies. Since all consumers possess the old product at the beginning of period 1, the vendor can only sell the new product. The vendor may choose to sell the new product only in period 1, only in period 2, or in both periods. We consider it 'delayed purchasing' if consumers purchase the new product in period 2 which is available earlier in period 1. To price the new product, the vendor has three options: (1) premium pricing -- a high price that is only affordable to the high type; (2) pooling pricing -- a low price that is affordable to both types; (3) intertemporal price discrimination -- selling to the high and low types sequentially with different prices. The possible combinations of timing and pricing strategies are listed in Table 1a.

There are altogether four product introduction schedules denoted as A1, ..., A4. Without commitment on its subsequent product introduction schedule, the vendor has the incentive to capture the remaining demand in period 2 by cutting the price (i.e., it faces a standard time inconsistency problem). Thus the product introduction schedule of only selling the new product in period 1 with premium pricing cannot form a sub-game perfect equilibrium. Table 1b lists the respective equilibrium outcomes of strategies A1 to A4 in terms of consumers' purchase sequence. For instance,

strategy A2 has two sub-columns. The ‘H’ column states that the high type will purchase the new (denoted as  $N$ ) product in period 1; and the ‘L’ column states that the low type will purchase the new product in period 2.

**Table 1a Vendor’s Feasible Strategies with a Fully-Covered Installed Base**

Vendor’s strategies given a fully covered installed base		TIMING			
		Period 1 only	Period 2 only	Both periods	
PRICING	Corner solutions	Premium pricing	—	A4	—
		Pooling pricing	A1	A3	—
	Intertemporal price discrimination	—	—	A2	

**Table 1b Users’ Feasible Actions with a Fully-Covered Installed Base**

Period	Possible Outcomes							
	A1		A2		A3		A4	
	H	L	H	L	H	L	H	L
1	N	N	N	—	—	—	—	—
2	—	—	—	N	N	N	N	—

The prices and the corresponding profits for strategies A1, A3 and A4 are straightforward. As for strategy A2, by backward induction, we can derive the price in period 2:

$$p_2^N = u_{N2}^L,$$

which is the low type’s reservation price.

The price of the new product in period 1 is subject to self-selection:

$$U_{N1}^H - p_1^N \geq U_{N2}^H - \delta p_2^N \quad (7)$$

$$U_{N2}^L - \delta p_2^N \geq U_{N1}^L - p_1^N \quad (8)$$

Equation (7) states that the surplus that the high type obtains from purchasing the new product in period 1 (the left hand side of (7)) should be no less than what they would get if they purchase it in period 2 (the right hand side of equation (7)). Similarly, equation (8) is to ensure that the low type are better off by purchasing in period 2 than in period 1. By equations (7) and (8), the maximum price that the vendor can charge the high type is:

$$p_1^N = U_{N2}^L - \Delta U_{Nt}^H / \Delta t \quad (9)$$

which is feasible if and only if  $\Delta U_{Nt}^H / \Delta t \leq 0$ , or  $q_0 \leq q_2$ .

The sub-game perfect equilibrium strategies are determined by consumers' relative willingness to pay for the new product and their relative payoffs from delayed purchase. By equations

(4) and (6),  $U_{Nt}^H > U_{Nt}^L$ , and

$$\left| \frac{\Delta U_{Nt}^H}{\Delta t} \right| \geq \left| \frac{\Delta U_{Nt}^L}{\Delta t} \right| \text{ or } \begin{cases} 0 < \frac{\Delta U_{Nt}^L}{\Delta t} < \frac{\Delta U_{Nt}^H}{\Delta t}, \text{ if } q_o > q_2 \\ \frac{\Delta U_{Nt}^H}{\Delta t} \leq \frac{\Delta U_{Nt}^L}{\Delta t} \leq 0, \text{ if } q_o \leq q_2 \end{cases} \quad (10)$$

Equation (10) implies that with the same purchase history, the high type are more sensitive to the change in purchase timing than the low type. If the extent of quality improvement is sufficiently high ( $q_o \leq q_2$ ), both types would suffer from delayed purchase and the high type would lose relatively more than the low type. Hence, it is always profitable to serve the high type no later than the low type. On the other hand, if the extent of quality improvement is not high ( $q_o > q_2$ ), both types are better off from delayed purchase, and the high type will gain relatively more from delayed purchase than the low type. However, it is infeasible to serve the high type later since they are able to purchase the new product at any price that is affordable to the low type and get a positive surplus. In equilibrium, either both types buy simultaneously, or only the high type buy in the last period. Lemma 1 summarizes the low and high types' purchase patterns in the presence of a fully-covered installed base.

**Lemma 1.** In the presence of a fully-covered installed base of the old product, the high type are more sensitive to the change in purchase timing than the low type. The high type will purchase the new product no later than the low type. Specifically, intertemporal price discrimination is feasible only if the extent of quality improvement is sufficiently high ( $q_o \leq q_2$ ).

We summarize the price sequences and profits of strategies A1-A4 in Table 2. Comparing these profits leads to the optimal strategies as presented in Proposition 2.

<Insert Table 2>

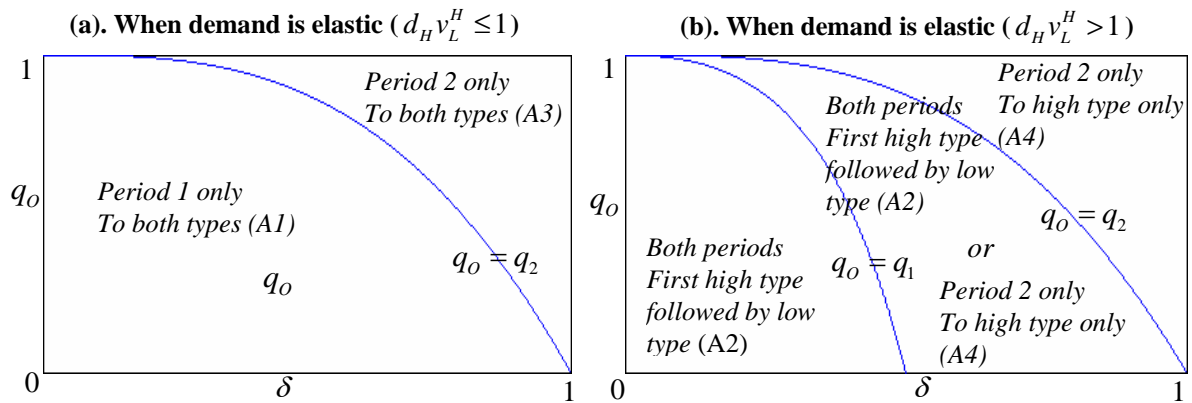
**Proposition 2.** In the presence of a fully-covered installed base of the old product, the conditions under which each strategy dominates the others are given in Table 3:

**Table 3. The Optimal Strategies in the Presence of a Fully-covered Installed Base**

	The extent of quality improvement	Optimal Strategy		
		No.	Timing	Sell to
Elastic demand ( $d_H v_L^H \leq 1$ )	$q_o > q_2$	A3	Period 2 only	Both types
	$q_o \leq q_2$	A1	Period 1 only	Both types
Intermediate case ( $1 < d_H v_L^H \leq l$ )	$q_o \leq q_2$	A2	Both periods	First high type followed by low type
Inelastic demand $d_H v_L^H > \max\{1, l\}$	$q_o > q_1$	A4	Period 2 only	High type only
	$q_o \leq q_1$	A2	Both periods	First high type followed by low type

where  $l = \frac{\delta \{ [1 - \delta^n] - [1 - \delta^{n-2}] q_o \}}{[2\delta - 1][1 - \delta^n] - [2\delta - 1 - \delta^{n-1}] q_o}$ .  $l \geq 1$  if  $q_o \leq q_2$ .

Proposition 2 shows that, when consumers have the same purchase history, whether the vendor exercises price discrimination is determined by demand elasticity ( $d_H v_L^H$ ). If the demand is elastic ( $d_H v_L^H < 1$ ), penetration pricing (A1 and A3) can maximize the vendor's profit by capturing the entire demand with a low price. If the demand is inelastic ( $d_H v_L^H \geq 1$ ), the vendor can earn more profit from the high type and at the same time capture the demand of the low type if the extent of quality improvement is high (A2). As for timing, instead of launching the new product in period 1, the vendor may choose to delay the introduction to period 2 (A3 or A4). When the extent of quality improvement is low, delayed introduction mainly serves to raise consumers' willingness to purchase the new product (A3). When both the extent of quality improvement and consumer heterogeneity are high, delayed introduction ensures a non-decreasing price of the new product (A4).



**Figure 2. Conditions of Optimal Strategies with a Fully-covered Installed Base (n=3)**

Referring to Figure 2(a), given elastic demand (i.e.,  $d_H v_L^H \leq 1$ ), the vendor sets a low price to capture the entire demand. The rationale for delayed introduction is similar to the one proposed by Hui and Wang (2005): postponing the introduction of the new product allows the old product to be used for one more period, and hence the old product depreciates more in value; consumers who possess the old product would then be willing to pay more to upgrade to the new product in a later period. This allows the vendor to charge a relatively higher price for the new product and earn more profit. By Proposition 1, in the region  $q_o > q_2$ , users' payoff from delayed purchase is positive, and so is the vendor's profit.

Referring to Figure 2(b), when demand is inelastic, i.e.,  $d_H v_L^H > 1$ , the vendor sets a relatively high price which is unaffordable to the low type in order to capture the premium profit from the high type. Interestingly, compared to the case when demand is elastic, the vendor may prefer to delay the introduction of the new product (A4) even when the quality improvement is not low ( $q_1 < q_o \leq q_2$ ). In this case, other than cannibalization from the stock of the old product, it is consumers' anticipation of future price reduction and the vendor's incapability of commitment that further force the vendor to delay selling the new product. On one hand, the high type are capable to pay a relatively high price for the new product. On the other hand, being aware of the vendor's incentive of lowering the price in the subsequent period (to attract the low type), the high type are unwilling to pay a high price in the early period. The lucrative benefit from extracting the full surplus of the high type induces the vendor to delay the launching of the new product. This strategy eliminates the vendor's own incentive of lowering the price in the planning horizon (and hence it resolves the time inconsistency problem that it faces), thus enables the equilibrium with premium pricing.

From consumers' perspective, in some circumstances, their rationale about price reduction may cause them to be inefficiently served. Similar to Moorthy and Png (1992), the efficient purchase sequence (including purchase timing and products) is the one that can maximize consumers' utility given their purchase history and the current technology level. For instance, in the presence of a fully-covered installed base, either the low or high type are efficiently served if:

- they purchase the new product in period 1 when  $q_o \leq q_2$ ;

— they purchase the new product in period 2 when  $q_o > q_2$ .

Consumers' utility in the above two cases are  $U_{N1}^e$  and  $U_{N2}^e$ ,  $e = H, L$ , respectively. Corollary 1 summarizes these findings.

**Corollary 1.** In the presence of a fully-covered installed base of the old product, when the demand is elastic ( $d_H v_L^H \leq 1$ ), both consumer types can get efficient utility. Otherwise, the low type always gets inefficient utility. The high type gets inefficient utility when the demand is very inelastic ( $d_H v_L^H \geq \max\{1, l'\}$ ) and the extent of quality improvement is moderate ( $q_1 < q_o < q_2$ ).

It is useful to compare Proposition 2 with the vendor's optimal strategies in the absence of an installed base ( $q_o = 0$ ). According to equation (2), a consumer's discounted utility at period 1 from consuming the new product in period  $t$  is  $Z_{Nt}^e = v_e \delta^{t-1} [1 - \delta^n] / [1 - \delta]$ ,  $t = 1, 2$ ,  $e = H, L$ . The possible introduction strategies in this case are the same as those listed in Table 1a. Obviously, strategy A3 is dominated by strategy A1. Comparing the profits generated by strategies A1, A2, and A4, we characterize the conditions in which each strategy dominates the others in Table 4.

**Table 4. The optimal strategies in the absence of an installed base**

	Discount factor	Optimal Strategy		
		No.	Timing	Sales
Elastic demand ( $d_H v_L^H \leq 1$ )		A1	Period 1 only	Both types
Intermediate case ( $1 < d_H v_L^H \leq l'$ )	$\delta > \frac{1}{2}$	A2	Both periods	First high type followed by low type
Inelastic demand $d_H v_L^H > \max\{1, l'\}$	$\delta > \frac{1}{2}$	A4	Period 2 only	High type only
	$\delta \leq \frac{1}{2}$	A2	Both periods	First high type followed by low type

where  $l' = \delta / [2\delta - 1] > l$ .

Table 4 provides a benchmark for examining how an installed base affects the optimality of second-degree price discrimination. Comparing the results in Tables 3 and 4, we find that the region in which

A2 is optimal shrinks in the presence of a fully-covered installed base. Proposition 3 formally confirms our speculation following Proposition 1.

**Proposition 3.** In the presence of a fully-covered installed base, it is more difficult to practice intertemporal price discrimination than the case with no installed base.

## 4.2 A Partly-Covered Installed Base

We now consider the case in which the high type have purchased the old product in period 0 but the low type have not. In this case, other than timing and pricing only the new product, the vendor could also sell the old product to the low type. The possible combinations of timing, pricing and product line strategies are summarized in Table 5a as strategies B1, ..., B8. Table 5b lists the respective equilibrium outcomes of these strategies in terms of consumers' purchase sequence. For instance, in Table 5b, two sub-columns are listed under strategy B4. The '*H*' column states that the high type will purchase the new product in period 2; the '*L*' column states that the low type will purchase the new product in period 1. We exclude the strategies in which the low type purchase nothing or purchases the old product in period 2 because they cannot form a sub-game perfect equilibrium<sup>9</sup>.

**Table 5a Vendor's Feasible Strategies with a Partly-Covered Installed Base**

Vendor's strategies given a partly covered installed base			PRODUCT LINE	TIMING of new product		
				Period 1 only	Period 2 only	Both periods
PRICING of new product	Corner solutions	Premium pricing	both products	—	B6	—
			new product only	—	B8	—
		Penetration pricing	both products	—	B5	—
			new product only	B1	B7	—
	Intertemporal price discrimination	High type first followed by Low type	both products	—	—	B2
			new product only	—	—	B3
		Low type first followed by High type	both products	—	—	—
			new product only	—	—	B4

<sup>9</sup>Suppose there exists an equilibrium in which the vendor sells the new product only to the high type, then the vendor must sell it in period 2. Otherwise, the vendor can always capture the remaining demand from the low type by selling the new product with any positive price in period 2. Further, the low type will always purchase the old product in period 1 because the price of the old product will not decrease (in period 2 the high type are only interested in the new product) and the price of the new product in period 2 will be affordable only to the high type.

**Table 5b Users' Feasible Actions with a Partly-Covered Installed Base**

Period	B1		B2		B3		B4		B5		B6		B7		B8	
	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L
1	N	N	N	O	N	-	-	N	-	O	-	O	-	-	-	-
2	-	-	-	N	-	N	N	-	N	N	N	-	N	N	-	N

Since the low and high types differ in their purchase history, the vendor may employ an upgrade policy to distinguish consumers who have purchased or not purchased the old product (Fudenberg and Tirole 1998). We separate our analysis into two scenarios. In the first scenario, the vendor cannot provide an upgrade option to consumers. Hence, all consumers must pay the same price for the new product. In the second scenario, the vendor can offer an upgrade policy, which allows consumers to trade in the old product for the new product at a discounted price. In this case, we can examine how price discrimination on purchase history interacts with consumers' valuation of quality to affect product timing in a heterogeneous market -- an outstanding question that was posed by Fishman and Rob (2000).

Lemma 2 characterizes the demand for the new product in a market with a partly-covered installed base.

**Lemma 2.** In the presence of a partly-covered installed base, the willingness of the high type to purchase the new product is lower than that of the low type in period 1 (period 2) if and only if  $v_L^H < v_2$  ( $v_L^H < v_1$ ). The low type are always worse off from delayed purchase of the new product. The high type are worse off from delayed purchase of the new product if and only if  $q_0 < q_2$ , and they suffer even more than the low type if  $v_L^H > v_3$ .

Table 6 illustrates Lemma 2. The columns of Table 6 define the intervals of consumer heterogeneity ( $v_L^H$ ) by the relative utility of the high and low types derived from the new product (comparing  $U_{Nt}^H$  with  $Z_{Nt}^L$ ,  $t = 1, 2$ ). It shows that the utility of the high type derived from the new product is not necessarily higher than that of the low type unless their high valuation on quality outweighs the balking effect caused by the existing stock of the old product (e.g.,  $v_L^H > v_3$ ). Further, the relative utility between the high and low types varies with purchase timing due to the depreciation of the

existing stock of the old product (e.g., in column  $v_1 < v_L^H \leq v_2$ ,  $U_{N1}^H \leq Z_{N1}^L$  but  $U_{N2}^H > Z_{N2}^L$ ). The rows of Table 6 define the intervals of the extent of quality improvement ( $q_o$ ) by the high type's payoff from delayed purchase (comparing  $\Delta U_{Nt}^H / \Delta t$  with 0). The combined effects of consumer heterogeneity and the extent of quality improvement generate seven distinctive regions in Table 6. In particular, although both types suffer from delayed purchase in row  $q_o \leq q_2$ , the high type's loss is *less* than the low type's if the balking effect caused by the existing stock of the old product exceeds their high valuation on product quality (e.g., with  $v_L^H \leq v_3$ ,  $\Delta Z_{Nt}^L / \Delta t \leq \Delta U_{Nt}^H / \Delta t < 0$ ). This is contrary to Lemma 1 which suggests that the high type are more sensitive to purchase timing given a fully covered installed base. The specific demand structure in a market with a partly-covered installed as presented in Table 6 is the basis of the pricing strategies discussed in subsequent subsections. The variation in demand may lead to different pricing functions even for the same product introduction schedule, which contributes to the diversified conditions under which intertemporal price discrimination or upgrade pricing is optimal.

**Table 6. Properties of the Regions Defined by  $(v_L^H, q_o)$  in the Presence of a Partly-covered Installed Base.**

$q_o \backslash v_L^H$	$v_L^H \leq v_1$	$v_1 < v_L^H \leq v_2$	$v_2 < v_L^H \leq v_3$	$v_L^H > v_3$
$q_o > q_2$	$U_{N1}^H < Z_{N1}^L$ $U_{N2}^H \leq Z_{N2}^L$ $\frac{\Delta Z_{Nt}^L}{\Delta t} < 0 \leq \frac{\Delta U_{Nt}^H}{\Delta t}$	$U_{N1}^H \leq Z_{N1}^L$ $U_{N2}^H > Z_{N2}^L$ $\frac{\Delta Z_{Nt}^L}{\Delta t} < 0 \leq \frac{\Delta U_{Nt}^H}{\Delta t}$	$U_{N1}^H > Z_{N1}^L$ $U_{N2}^H > Z_{N2}^L$ $\frac{\Delta Z_{Nt}^L}{\Delta t} < 0 \leq \frac{\Delta U_{Nt}^H}{\Delta t}$	
$q_o \leq q_2$	$U_{N1}^H < Z_{N1}^L$ $U_{N2}^H \leq Z_{N2}^L$ $\frac{\Delta Z_{Nt}^L}{\Delta t} \leq \frac{\Delta U_{Nt}^H}{\Delta t} < 0$	$U_{N1}^H \leq Z_{N1}^L$ $U_{N2}^H > Z_{N2}^L$ $\frac{\Delta Z_{Nt}^L}{\Delta t} \leq \frac{\Delta U_{Nt}^H}{\Delta t} < 0$	$U_{N1}^H > Z_{N1}^L$ $U_{N2}^H > Z_{N2}^L$ $\frac{\Delta Z_{Nt}^L}{\Delta t} \leq \frac{\Delta U_{Nt}^H}{\Delta t} < 0$	$U_{N1}^H > Z_{N1}^L$ $U_{N2}^H > Z_{N2}^L$ $\frac{\Delta U_{Nt}^H}{\Delta t} \leq \frac{\Delta Z_{Nt}^L}{\Delta t} < 0$

#### 4.2.1 With No Upgrade Policies

If the vendor cannot identify consumers who have previously bought the old product, or if the administrative cost of trade-in is too high, it may not offer an upgrade discount to existing consumers.

All consumers must pay the same price for the new product, and hence  $p_1^{Nu} = p_1^N$  and  $p_2^{Nu} = p_2^N$ .

Consider the possible strategies listed in Table 5a:

(1) Strategy B1 (selling the new product to both types in period 1) requires a common price that extracts the full surplus from the consumer type with a lower reservation price for the new product.

By Proposition 4, when  $v_L^H < v_2$ , the willingness of the high type to purchase the new product is lower than that of the low type ( $U_{N1}^H < Z_{N1}^L$ ), and hence we have  $p_1^N = U_{N1}^H$ ; otherwise,  $p_1^N = Z_{N1}^L$ .

(2) With strategies B2 or B3, the vendor sells the new product to the high type in period 1 and low type in period 2. For strategy B2, the vendor further sells the old product to the low type in period 1.

Note that without possessing the old product at the beginning of the game, the low type would have a higher reservation price for the new product compared to the case with a fully covered installed base ( $U_{Nt}^L < Z_{Nt}^L$ ). This exacerbates the problem of intertemporally price discriminating the two types of consumers when compared with the setting in Proposition 3 (in which both consumer types possess the old product in period 1). Lemma 3 formalizes this finding.

**Lemma 3.** Given a partly-covered installed base of the old product, with no upgrade policy, selling the new product in both periods by first serving the high type in period 1 (B2 or B3) is feasible if and only if the extent of quality improvement is sufficiently high, i.e.,  $q_o \leq q_2$ . Further, if the extent of consumer heterogeneity is not high, i.e.,  $v_L^H \leq v_3$ , the vendor has to compensate the low type by selling them the old product with a very low price in period 1 (B2).

Lemma 3 results from two forces that suppress the vendor's monopoly power to temporally differentiate the two types of users by first serving the high type:

One is the *mutual arbitrage* between the low and high types. Anticipating future price reduction (i.e., the time inconsistency problem as characterized in Coase 1972, Bulow 1982, etc.), the high type have the incentive to postpone their purchase of the new product to period 2. To attract the high type to purchase in period 1 (B2 or B3), the vendor has to restrict the price ( $p_1^N$ ) of the new product in period 1 so as to leave the high type some positive surplus that is no less than what they

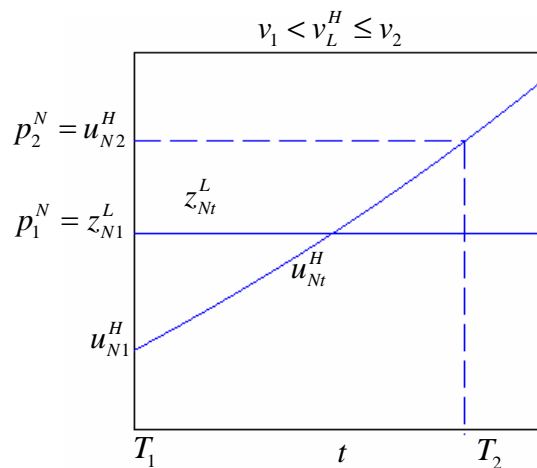
would gain from waiting until period 2 (constraint (A7)). However, if the consumers are relatively homogeneous, i.e.,  $v_L^H \leq v_3$ , the relatively low price of the new product offered to the high type ( $p_1^N$ ) may attract the low type to directly purchase the new product in period 1 too. In this case, the low type would lose even more than the high type from delayed purchase ( $\Delta Z_{Nt}^L / \Delta t \leq \Delta U_{Nt}^H / \Delta t < 0$  as shown in the region  $R(v_L^H \leq v_3, q_O \leq q_2)$  in Table 6). Hence, the reservation price of the low type for the new product in period 1 ( $Z_{N1}^L = \delta p_2^N - \Delta Z_{Nt}^L / \Delta t = U_{N2}^L - \Delta Z_{Nt}^L / \Delta t$ ) is higher than the maximum price that the vendor can charge the high type in period 1 ( $p_1^N = \delta p_2^N - \Delta U_{Nt}^H / \Delta t$ ). To prevent the low type from deviating (i.e., purchasing the new product in period 1), the only measure that the vendor can use is to further reduce the price of the old product to ensure that the low type can be compensated for waiting until the last period to buy the new product (see B2 and constraint (A5)).

Nonetheless, selling the old product in period 1 induces a *mutual cannibalization* between the old and new products. On one hand, anticipating the forthcoming of the new product, the low type may bypass the old product and wait for the new one. On the other hand, the existing stock of old product limits their willingness to purchase the new product. This further constrains the prices ( $p_1^O, p_2^N$ ) that the vendor can charge the low type for the old and new products (constraints (A4) and (A6)).

**(3)** Contrary to strategy B3, with strategy B4, the vendor sells the new product in two periods by first serving the low type. By Proposition 4 and Table 6, the willingness of the low type to purchase the new product is higher than that of the high type in both periods if  $v_L^H \leq v_1$ , and only in period 1 if  $v_1 < v_L^H \leq v_2$ . We highlight an interesting property of strategy B4 in Lemma 4.

**Lemma 4.** Given a partly-covered installed base of the old product, with no upgrade policy, selling the new product in both periods by first serving the low type in period 1 (B4) is feasible if and only if  $v_L^H \leq v_2$ . Further, if  $v_1 < v_L^H \leq v_2$ , the vendor achieves perfect intertemporal price discrimination.

The perfect intertemporal price discrimination by sequentially first selling the new product to the low type followed by the high type (B4) is the direct result of the high-type' increasing need to upgrade. As shown in Figure 3, when the heterogeneity in valuation of quality is sufficiently high, i.e.,  $v_L^H > v_1$ , the vendor can extract the full surplus from the low type and leave them with little choice because they have to face an *even higher* price in the subsequent period ( $p_2^N = u_{N2}^H > z_{N2}^L$ ) as the willingness of the high type to purchase the new product increases ( $\Delta U_{Nt}^H / \Delta t > 0$ ) over time. Further, if the heterogeneity in valuation of quality is not too high (e.g.  $v_L^H \leq v_2$ ), the high type are unwilling to accept the price in the early period because it is higher than the incremental utility that they can get from the new product at that time ( $p_1^N = z_{N1}^L > u_{N1}^H$ ). Thus they have to wait and purchase the new product after the low type. Because the high type's willingness to purchase increases over time while the low type's remains unchanged (because they do not possess the old product), in the region  $R(v_1 < v_L^H \leq v_2, q_0)$ , the reservation price of the high type for the new product changes from being lower than that of the low type in period 1 to being higher than it in period 2. The high type's increasing need for the new product enables perfect intertemporal price discrimination by which the vendor can extract the full surplus of both consumer types derived from the new product.



**Figure 3. Consumers' Willingness to Purchase the New Product**

Lemma 3 and 4 highlight an interesting and unique characteristic of intertemporal price discrimination in a market with a partly-covered installed base. Similar to Proposition 3, the

increasing need for upgrade makes intertemporal price discrimination more difficult. Different from the case of a fully-covered installed base, however, the low and high type consumers, being heterogeneous not only in valuation of quality but also in purchase history, exhibit respectively a constant trend and an increasing trend in their willingness to purchase the new product (as shown in Figure 3). Thus there exists a certain parameterization of heterogeneity that favors another type of intertemporal price discrimination – one in which the low type with no purchase history consume the new product earlier. It is important to note that this intertemporal price discrimination can be perfect, and the vendor extracts all surplus from consumers.

(4) Strategies B5, B6, B7 and B8 are characterized with delayed introduction of the new product. Both strategies B5 and B6 sell the old product to the low type in period 1. Similar to strategy B2, the price sequence of strategy B5 is subject to the mutual cannibalization between the old and new products. Strategy B5 results in a pooling equilibrium in which both types purchase the new product in period 2 with a price equal to the low type's willingness of upgrading to the new product ( $p_2^N = u_{N1}^L$ <sup>10</sup>). By contrast, strategy B6 leads to a separating equilibrium in which only the high type purchase the new product with a price equal to their incremental utility derived from the new product ( $p_2^N = u_{N2}^H$ ). In strategy B5, both types are left with positive surplus. In strategy B6, the surplus of both types is fully extracted if the low type cannot afford the price of the new product in period 2 ( $v_L^H > v_1$ ); otherwise, the low type can get positive surplus. As for strategies B7 and B8, the vendor would not sell any product in period 1. Similar to strategy B1, B7 (selling the new product to both types in period 2) requires a common price that extracts the full surplus from the type of consumer who has a relatively lower reservation price for the new product in period 2. Strategy B8 sells only the new product to the low type; by Proposition 4, it is feasible only when  $v_L^H \leq v_1$ .

The price sequences and profits for strategies B1-B8 are listed in Table 7. Comparing their profits leads to proposition 4.

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<sup>10</sup> Having purchased the old product in period 1, the low type's willingness of purchasing the new product in period 2 is equivalent to  $u_{N1}^L = v_L \frac{[1 - \delta^n]}{[1 - \delta]} - q_o v_L \frac{[1 - \delta^{n-1}]}{[1 - \delta]}$ ; its corresponding utility in the present value terms of period 1 is equivalent to  $\delta U_{N1}^L$ .

<Insert Table 7>

**Proposition 4.** With a partly-covered installed base of the old product, and with no upgrade policy, for each region defined by  $R(v_L^H, q_o)$ , the optimal strategies given the different demand elasticities are presented in Table 8. Specifically, regardless of consumer heterogeneity, strategy B2 (B8) is always better than strategy B3 (B5) when the size of the low type is sufficiently large.

**Table 8. Optimal Strategy with No Upgrade Policy in the Presence of a Partly-covered Installed Base.**<sup>11</sup>

$v_L^H \backslash q_o$	$v_L^H \leq v_1$	$v_1 < v_L^H \leq v_2$	$v_2 < v_L^H \leq v_3$	$v_L^H > v_3$
$q_o \geq q_2$	$\leftarrow$ B5, B8 $\rightarrow$   B4 $\rightarrow$	<b>B4</b>		$\leftarrow$ B1 $\rightarrow$   B6 $\rightarrow$ $d_H v_L^H$
$q_1 \leq q_o < q_2$	$\leftarrow$ B4 $\rightarrow$   B1 $\rightarrow$ $d_H v_L^H$			$\leftarrow$ B1 * B2, B3 $\rightarrow$   B6 $\rightarrow$ $d_H v_L^H$
$q_o < q_1$				$\leftarrow$ B1 * B6 * B2, B3 $\rightarrow$ $d_H v_L^H$

Proposition 4 shows that the conditions under which a specific strategy is optimal are defined by the extent of quality improvement, consumer heterogeneity, and demand elasticity. For instance, in the region  $R(v_L^H > v_3, q_1 \leq q_o < q_2)$ , strategy B1 can be optimal when the demand is relatively elastic. As the demand elasticity decreases, strategy B2 or B3 may become optimal. Strategy B6 is optimal when the demand is relatively inelastic. It is useful to highlight some interesting observations implied by Proposition 4.

**(Delayed product introduction)** Delayed introduction of the new product is not optimal in the region with moderate heterogeneity,  $R(v_1 < v_L^H \leq v_2, q_o)$ , or the region with relatively low heterogeneity and high quality improvement,  $R(v_L^H \leq v_1, q_o < q_2)$ . It can be optimal either in the region  $R(v_L^H \leq v_1, q_o \geq q_2)$  or the region  $R(v_L^H > v_2, q_o)$  but with very different reasons.

<sup>11</sup> The detailed analysis of the conditions under which each strategy is optimal is presented in the Appendix 3 for review purpose.

When both consumer heterogeneity and the extent of quality improvement are low ( $v_L^H \leq v_1, q_O \geq q_2$ ), strategy B5 outperforms the other strategies because the vendor can profit from selling the old product in period 1 and capturing the entire demand with a common price in period 2. When the low type are dominant (i.e., they have a “large” representation in the consumer population), the vendor may even sell only to the low type in the last period (B8).

When the extent of consumer heterogeneity is high ( $v_L^H > v_2$ ), strategy B6 can be optimal regardless of the extent of quality improvement. The profit in strategy B6 consists of two parts: one is the sale of the new product to the high type in period 2; the other is the sale of the old product to the low type in period 1. In the region  $R(v_L^H > v_2, q_O \geq q_1)$ , strategy B6 outperforms the other strategies mainly because of the contribution from selling the new product. The reason behind delayed introduction is similar to that discussed in Section 4.1 – by postponing the introduction of the new product, the vendor can raise the price of the new product either because of the increasing discounted utility that consumers derive from the new product ( $\Delta U_{Nt}^H / \Delta t \geq 0$  in the region  $R(v_L^H, q_O \geq q_2)$ ), or because it relieves the high type consumers’ concern about future price reductions (region  $R(v_L^H > v_2, q_1 \leq q_O < q_2)$ ). By contrast, in the region  $R(v_L^H > v_2, q_O < q_1)$ , strategy B6 cannot outperform strategies B2 and B3 unless the profit from selling the old product to the low type in period 1 is sufficiently large. To make delayed introduction optimal in  $R(v_L^H > v_2, q_O < q_1)$ , the extent of quality improvement cannot be too high, and, at the same time, the discount factor should be small enough while the size of the low type should be large.

Since the advantage of delayed introduction (B6) compared with the other strategies vary with the extent of quality improvement, strategy B6 is optimal when the demand elasticity is lower than that of strategies B1, B2 and B3 in the region  $R(v_L^H > v_2, q_O \geq q_1)$ . A relatively high demand elasticity would also favor strategy B6 in the region  $R(v_L^H > v_2, q_O < q_1)$ .

Delayed introduction where the new product is sold to both consumers types and the old product is not sold (i.e., B7) can never be optimal. This is because when compared with strategy B7,

with relatively low consumer heterogeneity ( $v_L^H \leq v_2$ ), strategy B4 would provide more profit to the vendor due to the low type's early purchase of the new product; with relatively high consumer heterogeneity ( $v_L^H > v_2$ ), strategy B1 is more profitable by letting both consumer types purchase in period 1.

**(Perfect intertemporal price discrimination)** Selling the new product in both periods by first serving the low type in period 1 (B4) dominates the other strategies regardless of segment sizes in the region  $R(v_1 < v_L^H \leq v_2, q_o \geq q_2)$ . By Lemma 4, it also leads to perfect price discrimination. Similar to strategy B6, the advantage of strategy B4 relative to the other strategies in the region  $R(v_L^H \leq v_2, q_o)$  varies with the extent of quality improvement. If  $q_o \geq q_2$ , strategy B4 is optimal when the demand elasticity is relatively low (cf. strategy B5 and B8); if  $q_o < q_2$ , it is optimal when the demand elasticity is relatively high (cf. strategy B1).

Setting aside the above properties about delayed introduction and perfect intertemporal price discrimination, we next consider the social efficiency of the optimal strategies in Proposition 4. Referring to Proposition 1, the vendor's strategy is socially efficient if it chooses strategy B5 in the region  $R(v_L^H, q_o > q_2)$  and strategy B1 in the region  $R(v_L^H, q_o \leq q_2)$ . However, as shown in Table 8, for some regions defined by  $v_L^H$  and  $q_o$ , the outcome is not efficient. Generally, due to the mutual cannibalization between the old and new products and the possible arbitrage between the low and high type consumers, in most of the parameter spaces, the vendor is unable to extract the full surplus from the consumers. The allocation of surplus between the vendor, the low type, and the high type induces the vendor to extract more surplus by choosing inefficient strategies. For instance, to avoid the mutual cannibalization between the old and new products, it may shelve the old product when it is indeed efficient to sell it to the low type (e.g., B4 in the region  $R(v_L^H \leq v_2, q_o > q_2)$ ); similarly, to eliminate the concern of future price reduction, the vendor may delay the introduction of the new product even though it is efficient to launch it immediately in period 1 (e.g., B6 in the region

$R(v_L^H > v_2, q_o \leq q_2)$ ). This confirms Fishman and Rob's conjecture about the dampening effect of heterogeneity on monopoly profits.

#### 4.2.2 With An Upgrade Policy

We now consider the case when the vendor can implement an upgrade policy. The provision of the upgrade option is an extra instrument for a vendor to exercise price discrimination based on purchase history (Fudenberg and Tirole 1998, Lee and Lee 1998). If the vendor can identify consumers who have bought the old product, it can charge them only the incremental utility that they receive by using the new product. For those who do not own the old product, it can charge them the full utility.

In our setting, only the high type possesses the old product at the beginning of period 1. The implementation of upgrade policy can improve seller's profitability from two perspectives. First, the vendor can now make a credible threat to the low type that if they do not buy the old product in period 1, they will face a very high price of the new product in period 2 (cf. those who trade in the old product for the new product). This threat of price discrimination dissuades the low type from leapfrogging and encourages them to buy the old product as soon as it is available for purchase. Consequently, the upgrade policy can eliminate the cannibalization caused by the forthcoming new product on the old product, which in turn improves the profitability of strategies that sell both products to consumers, e.g., strategies B2 and B5 in Table 5b.

Second, upgrade policy encourages the high type to reveal their purchase history if their incremental utility from the new product is less than that of the low type. By this means, the vendor can easily differentiate the low and high types and charge the low type a higher price for the new product if they do not possess the old product. We expect that the presence of the upgrade policy can improve the profitability of product replacement strategies if the high type's incremental utility from the new product is less than that of the low type (e.g., strategies B1 and B4 in the region  $R(v_L^H \leq v_2, q_o)$ ). Compared to Lemma 3 in the case with no upgrade policy, Lemma 5 summarizes the difference caused by an upgrade policy.

**Lemma 5.** Given a partly-covered installed base, with an upgrade policy: (1) the surplus of the low type will always be fully extracted by the vendor (i.e. B4); (2) selling the new product to the high and low types in period 1 and period 2 respectively (i.e., B2 and B3) is always feasible.

Nevertheless, upgrade policy is not omnipotent. The high type will choose to conceal their purchase history if their incremental utility from the new product is still larger than that of the low type. We elaborate this point in Lemma 6.

**Lemma 6.** Given a partly-covered installed base, upgrade policy is incapable to segment users by their purchase history if user heterogeneity is sufficiently high, i.e., when  $U_{N_t}^H > Z_{N_t}^L$ .

Table 9 lists the price sequence and profit for each strategy (B1-B8). The direct effect of Lemma 6 is that some strategies among B1-B8 would not be influenced by the presence of upgrade policy. Comparing Tables 7 and 9, Lemma 7 lists the strategies where the price sequences remain unchanged in the absence/presence of upgrade policy.

<Insert Table 9>

**Lemma 7.** The price sequences of the following strategies would not be affected by the presence of an upgrade policy: (1) Strategy B1 in the region  $v_L^H > v_2$ ; (2) Strategy B3 in the region  $v_L^H > v_3$  and  $q_o \leq q_2$ ; (3) Strategy B4 in the region  $v_1 < v_L^H \leq v_2$  and  $q_o > q_2$ ; (4) Strategy B6 in the region  $v_L^H > v_2$  and  $q_o > q_1$ .

In particular, by Lemma 4, in the region  $v_1 < v_L^H \leq v_2$ , strategy B4 achieves perfect intertemporal price discrimination even with no upgrade policy. Comparing the profits listed in Table 9 leads to the following results.

**Proposition 5.** With a partly-covered installed base of the old product, and with an upgrade policy, for each region defined by  $R(v_L^H, q_o)$ , the optimal strategies given the different demand elasticities are presented in Table 10 below. Specifically, regardless of the extent of consumer heterogeneity,

strategy B2 (B5) is always better than strategy B3 (B1) when the segment size of the low type are large.

**Table 10. Optimal Strategy with an Upgrade Policy in the Presence of a Partly-covered Installed Base.**

$v_L^H$ $q_o$	$v_L^H \leq v_1$	$v_1 < v_L^H \leq v_2$	$v_2 < v_L^H \leq v_3$	$v_L^H > v_3$
$q_o \geq q_2$				
$q_1 \leq q_o < q_2$	<b>B1</b>			
$q_o < q_1$				

As expected, the upgrade policy improves the profitability of strategies that sell the entire product line, i.e., B2 and B5, and the profitability of product replacement strategies in the region with relatively low consumer heterogeneity, i.e., B1 and B4. Referring to Table 10, this is reflected by the expansion of the regions in which these strategies are optimal, as compared with Table 8. As a result, some strategies are squeezed out of the original regions, e.g., strategy B8 disappears from the region  $R(v_L^H \leq v_2, q_o \geq q_2)$  and B6 becomes suboptimal in the region  $R(v_L^H > v_3, q_o < q_1)$ .

Past studies have advocated the benefit of the upgrade policy in maximizing the vendor's profit and promoting socially efficient production in various settings (see, e.g., Waldman 1997, Lee and Lee 1998, Fishman and Rob 2000). By Table 10, we notice that the strategies listed in Lemma 2 can be optimal within certain ranges of demand elasticity. This suggests that, in a more general setting with rich parameterizations of consumer heterogeneity (cf. the high heterogeneity setting in Lee and Lee (1998), or the homogeneous setting in Fishman and Rob (2000)), the upgrade policy may not be a necessary condition for the monopolist vendor to maximize its profit. Referring to Table 10, denote  $d_H v_L^H(B_i, v_L^H, q_o)$ ,  $i = 1..8$ , as the range of demand elasticity in which strategy  $B_i$  is optimal given the parameterization  $(v_L^H, q_o)$ , Proposition 6 summarizes the conditions in which the upgrade policy is not optimal for the vendor.

**Proposition 6.** With a partly-covered installed base of the old product, suppose that the vendor is able to offer an upgrade policy. It will not use it in the following conditions:

- (1)  $v_1 < v_L^H \leq v_2$ ,  $q_O > q_2$ , and  $d_H v_L^H (B_4, v_L^H, q_O)$ ;
- (2)  $v_L^H > v_2$  and  $d_H v_L^H (B_1, v_L^H, q_O)$ ;
- (3)  $v_L^H > v_3$ ,  $q_O \leq q_2$ ,  $d_H v_L^H (B_3, v_L^H, q_O)$ , and  $d_L < \delta [1 - \delta^{n-1}] / [1 - \delta]$ ;
- (4)  $v_L^H > v_2$ ,  $q_O > q_1$ , and  $d_H v_L^H (B_6, v_L^H, q_O)$ .

The first condition in Proposition 6 refers to the parameterizations in which the *perfect intertemporal price discrimination* strategy outperforms the upgrade policy in maximizing the vendor's profit. Similarly, the second, third and fourth conditions suggest that given some parameterizations of  $v_L^H$ ,  $q_O$ , and  $d_H v_L^H$ , instead of the upgrade policy, a *penetration pricing strategy* (B1), an *intertemporal price discrimination strategy* (B3), or a *delayed introduction strategy* (B6), can maximize the vendor's profit.

Proposition 6 also implies that with its incentive to differentiate consumers, the vendor may not choose socially efficient strategies even if an upgrade policy is feasible. The inability of upgrade policy to segment consumers by their purchase history as proposed in Lemma 6 may lead to both types of consumers to be inefficiently served (see, e.g., strategy B6 in the region  $R(v_L^H, q_O \leq q_2)$ ). Referring to Tables 7 and 8, if the vendor can sustain its monopoly power, for example, in the region  $R(v_L^H \leq v_2, q_O \leq q_2)$ , via an upgrade policy, both types of consumers can obtain efficient quality. Otherwise, whether and which type of consumers are efficiently served is determined by demand elasticity. Generally, the high type tends to get efficient quality when the demand is inelastic, whereas both types of consumers are efficiently served when the demand is elastic.

## 5 Concluding Remarks

It is useful to highlight our results in light of the existing literature. First, in their study of recurrent innovation, Fishman and Rob (2000) conjecture that in the setting with heterogeneous consumers, the

monopolist may slow down the pace of innovation because of the combined (dampening) effect of the stock of durable goods in use, and consumers' anticipation of future price reductions. Nevertheless, they did not characterize the profit-maximizing strategies with heterogeneous consumers. Their conjecture has not been analytically validated because of analytical complexity.

This study confirms Fishman and Rob's conjecture. In particular, we find that there is a wide range of equilibria in which the vendor may forgo the chance of selling the new product earlier, and instead delay selling the new product (even though it is costless to sell it earlier) to a later period. Such delayed introduction strategies are optimal regardless of the extents of consumer heterogeneity and quality improvement.

Second, prior research has advocated the benefit of upgrade pricing in maximizing the vendor's profit and promoting socially efficient production in various settings (Waldman 1997, Lee and Lee 1998, Fishman and Rob 2000). However, in a more general setting with rich parameterizations of consumer heterogeneity (cf. the homogeneous setting in Fishman and Rob (2000)), we find that upgrade pricing may lose its ability to segment the market. If the heterogeneity on valuation of quality is sufficiently high, instead of upgrade pricing, the vendor would maximize its profit via intertemporal price discrimination, delayed introduction, or penetration pricing.

Third, studies on product timing and pricing have used both quality and time as segmentation variables (Stokey 1979, Moorthy 1984). In this literature, the reservation price of users for a new product decreases over time because of discounted future utility. To maximize profit, a vendor would first sell a new product to the high valuation consumers, and then inefficiently serve the low valuation consumers by distorting product quality (Moorthy and Png 1992). The high valuation consumers will always buy a new product before the low valuation consumers and get the efficient quality.

However, our key disposition is that if some consumers have already owned the existing (old) version of a durable product, their willingness to purchase the newly improved version could indeed increase over time. This is because the old product depreciates over time, which increases the need for consumers to upgrade to the new product. Further, if the market consists of consumers with different purchase history, their reservation prices for the new product may change with time in opposite directions. We show that these inconsistent trends among consumers may enable a perfect

intertemporal price discrimination strategy in which the vendor sells the new product sequentially by first serving the low valuation consumers who have not yet purchased anything in the previous period. When heterogeneity in consumer valuation is sufficiently high, the vendor might extract the full surplus from the low valuation consumers and leave them with little choice because they may face an even *higher* price in the subsequent period due to the increasing willingness of the high valuation consumers to purchase the new product.

On the other hand, if consumer heterogeneity is not too high, the high valuation consumers are unwilling to accept the price in the early period because it is higher than the incremental utility that they can derive from the new product at that time. Thus, they would wait and purchase the new product after the low valuation consumers. This incentive to postpone purchase may actually make them worse off, which is contrary to popular findings in the price discrimination literature (see, e.g., Moorthy 1984, Moorthy and Png 1992).

Fourth, prior research has assumed high heterogeneity on consumers' valuation of quality so as to exclude the cases in which the willingness of the low valuation consumers to purchase a new product is higher than that of the high valuation consumers who possess the old product (Waldman 1993, Lee and Lee 1998). This assumption greatly simplifies the analysis, but it raises an important question: in a moderately heterogeneous market, if the high valuation consumers have purchased the old product, how should the vendor time the new product? In this study, we characterize the properties of this market with respects to consumers' relative net utility derived from the new product and their relative payoff from delayed purchase. We find that if the extent of quality improvement is high, an upgrade policy can help the vendor extract the full surplus from both types of consumers and at the same time provide socially optimal outcomes. Otherwise, depending on demand elasticity, the vendor may delay the selling of the new product or first sell to the low valuation consumers.

Our findings provide useful guidelines for product managers who often have to consider the installed base of their existing products when selling new products. Instead of trying to manipulate product durability (as suggested in Bulow 1986 and Waldman 1996a), they may adopt flexible timing and pricing strategies to cope with the existing installed base. Our setting is applicable to IT products, especially those that depend heavily on components developed by external vendors. Sellers of these

products often cannot control when new technologies are invented and when old products will become obsolete. Hence, for them, product innovation and introduction are two separate decisions – they might not be able to endogenize the extent of product innovation, but they could always control the timing and pricing of the new products. Because IT vendors often face a huge installed base of existing customers using their previous products, they need to exercise extreme care when launching and pricing a new product that incorporates advanced technologies. With suboptimal strategies, they may greatly suffer from the combined dampening effects of the stock of durable goods in consumers' hand, and consumers' anticipation of future price reductions (i.e., time inconsistency). However, through proper timing, pricing and product line strategies, a vendor could even practice perfect price discrimination by exploiting existing consumers' increasing need to upgrade to the new product.

Based on economic theories of consumer segmentation and price discrimination, this study provides an effective framework to address product timing and pricing decisions in the presence of an installed base. An immediate direction for future research is to extend our model to a competitive market. It would also be interesting to consider settings in which the demand is uncertain, or when there is asymmetric information.

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## Appendix 1<sup>12</sup>

**Table 2. Prices and Profits with a Fully-covered Installed Base**

Strategy	Price sequence	Profit
<b>A1</b>	$p_1^N = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_o \right) v_L$	$\pi_{A1} = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_L \right) v_L$
<b>A2</b>	$q_o < (1-\delta^n)$ $p_1^N = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_o \right) v_L + (1-\delta^n - q_o) v_H$ $p_2^N = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_o \right) v_L$	$\pi_{A2} = \left[ \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_o \right) v_L + (1-\delta^n - q_o) v_H \right] d_H + \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_o \right) v_L d_L$
<b>A3</b>	$p_2^N = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_o \right) v_L$	$\pi_{A3} = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_o \right) v_L$
<b>A4</b>	$p_2^N = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_o \right) v_H$	$\pi_{A4} = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_o \right) v_H d_H$

**Table 7. Prices and Profits in a Partly-covered Installed Base with no Upgrade Policy**

Strategy	Price sequence	Profit
<b>B1</b>	$v_L^H \leq \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-1})q_o}$ $p_1^N = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_o \right) v_H$	$\pi_{B1} = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_o \right) v_H$

<sup>12</sup> The derivation of prices for each strategy is presented in Appendix 3 for review purpose.

	$v_L^H > \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-1})q_o}$	$p_1^N = \frac{1-\delta^n}{1-\delta} v_L$	$\pi_{B1} = \frac{1-\delta^n}{1-\delta} v_L$
<b>B2</b>	$q_o < 1-\delta^n$ and $v_L^H \leq \frac{1-\delta^n}{1-\delta^n - q_o}$	$p_1^O = (1-\delta^n - q_o)v_H - (1-\delta^n - q_o)v_L$ $p_1^N = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_o \right) v_L + (1-\delta^n - q_o)v_H,$ $p_2^N = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_o \right) v_L$	$\pi_{B2} = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_o \right) v_L$ $+ (1-\delta^n - q_o)v_H - (1-\delta^n - q_o)v_L d_L$
	$q_o < 1-\delta^n$ and $v_L^H > \frac{1-\delta^n}{1-\delta^n - q_o}$	$p_1^O = q_o v_L, p_2^N = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_o \right) v_L$ $p_1^N = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_o \right) v_L + (1-\delta^n - q_o)v_H,$	$\pi_{B2} = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_o \right) v_L + (1-\delta^n - q_o)v_H d_H + q_o v_L d_L$
<b>B3</b>	$q_o < 1-\delta^n$ and $v_L^H > \frac{1-\delta^n}{1-\delta^n - q_o}$	$p_1^N = \delta \frac{1-\delta^n}{1-\delta} v_L + (1-\delta^n - q_o)v_H, p_2^N = \frac{1-\delta^n}{1-\delta} v_L$	$\pi_{B3} = \delta \frac{1-\delta^n}{1-\delta} v_L + (1-\delta^n - q_o)v_H d_H$
<b>B4</b>	$v_L^H \leq \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-2})q_o}$	$p_1^N = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_o \right) v_H + (1-\delta^n)v_L,$ $p_2^N = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_o \right) v_H$	$\pi_{B4} = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_o \right) v_H + (1-\delta^n)v_L d_L$
	$v_L^H > \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-2})q_o}$ and $v_L^H \leq \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-1})q_o}$	$p_1^N = \frac{1-\delta^n}{1-\delta} v_L, p_2^N = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_o \right) v_H$	$\pi_{B4} = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_o \right) v_H d_H + \frac{1-\delta^n}{1-\delta} v_L d_L$

<b>B5</b>		$p_1^O = q_O v_L, p_2^N = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_O \right) v_L$	$\pi_{B5} = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_O \right) v_L + v_L q_O d_L$
<b>B6</b>	$v_L^H \leq \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-2})q_O}$	$p_1^O = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_O \right) v_H - \frac{1-\delta^n}{1-\delta} (\delta - q_O) v_L,$ $p_2^N = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_O \right) v_H$	$\pi_{B6} = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_O \right) v_H - \frac{1-\delta^n}{1-\delta} (\delta - q_O) v_L d_L$
	$v_L^H > \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-2})q_O}$	$p_1^O = \frac{1-\delta^n}{1-\delta} v_L q_O, p_2^N = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_O \right) v_H$	$\pi_{B6} = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_O \right) v_H d_H + \frac{(1-\delta^n)}{1-\delta} v_L q_O d_L$
<b>B7</b>	$v_L^H \leq \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-2})q_O}$	$p_2^N = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_O \right) v_H$	$\pi_{B7} = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_O \right) v_H$
	$v_L^H > \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-2})q_O}$	$p_2^N = \frac{1-\delta^n}{1-\delta} v_L$	$\pi_{B7} = \frac{\delta(1-\delta^n)}{1-\delta} v_L$
<b>B8</b>	$v_L^H < \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-2})q_O}$	$p_2^N = \frac{1-\delta^n}{1-\delta} v_L$	$\pi_{B8} = \delta \frac{1-\delta^n}{1-\delta} v_L d_L$

**Table 9 Prices and Profits in a Partly-covered Installed Base with an Upgrade Policy**

Strategy	Price sequence	Profit	
<b>B1</b>	$v_L^H \leq \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-1})q_O}$	$p_1^{Nu} = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_O \right) v_H, p_1^N = \frac{1-\delta^n}{1-\delta} v_L$	$\pi_{B1}^u = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_O \right) v_H d_H + \frac{1-\delta^n}{1-\delta} v_L d_L$
	$v_L^H > \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-1})q_O}$	$p_1^{Nu} = p_1^N = \frac{1-\delta^n}{1-\delta} v_L$	$\pi_{B1}^u = \frac{1-\delta^n}{1-\delta} v_L$

<b>B2</b>		$p_1^O = \frac{1-\delta^n}{1-\delta} q_O v_L, p_2^{Nu} = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_O \right) v_L,$ $p_1^{Nu} = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_O \right) v_L + \left( (1-\delta^n) - q_O \right) v_H$	$\pi_{B2}^u = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_O \right) v_L + (1-\delta^n - q_O) v_H d_H + \frac{1-\delta^n}{1-\delta} q_O v_L d_L$
<b>B3</b>	$v_L^H \leq \frac{(1-\delta^n)}{(1-\delta^n) - (1-\delta^{n-2}) q_O}$	$p_1^{Nu} = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_O \right) v_H, p_2^N = \frac{1-\delta^n}{1-\delta} v_L$	$\pi_{B3}^u = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_O \right) v_H d_H + \frac{\delta(1-\delta^n)}{1-\delta} v_L d_L$
	$v_L^H > \frac{(1-\delta^n)}{(1-\delta^n) - (1-\delta^{n-2}) q_O}$	$p_1^{Nu} = \frac{\delta(1-\delta^n)}{1-\delta} v_L + \left( (1-\delta^n) - q_O \right) v_H, p_2^N = \frac{1-\delta^n}{1-\delta} v_L$	$\pi_{B3}^u = \frac{\delta(1-\delta^n)}{1-\delta} v_L + \left( (1-\delta^n) - q_O \right) v_H d_H$
<b>B4</b>	$v_L^H \leq \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-1}) q_O}$	$p_1^N = \frac{1-\delta^n}{1-\delta} v_L; p_2^{Nu} = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_O \right) v_H$	$\pi_{B4}^u = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_O \right) v_H d_H + \frac{(1-\delta^n)}{1-\delta} v_L d_L$
<b>B5</b>		$p_1^O = \frac{1-\delta^n}{1-\delta} q_O v_L, p_2^{Nu} = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_O \right) v_L$	$\pi_{B5}^u = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-1}}{1-\delta} q_O \right) v_L + \frac{(1-\delta^n)}{1-\delta} v_L q_O d_L$
<b>B6</b>		$p_1^O = \frac{1-\delta^n}{1-\delta} v_L q_O, p_2^{Nu} = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_O \right) v_H$	$\pi_{B6}^u = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_O \right) v_H d_H + \frac{(1-\delta^n)}{1-\delta} v_L q_O d_L$
<b>B7</b>	$v_L^H \leq \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-2}) q_O}$	$p_2^{Nu} = \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_O \right) v_H, p_2^N = \frac{1-\delta^n}{1-\delta} v_L$	$\pi_{B7}^u = \delta \left( \frac{1-\delta^n}{1-\delta} - \frac{1-\delta^{n-2}}{1-\delta} q_O \right) v_H d_H + \frac{\delta(1-\delta^n)}{1-\delta} v_L d_L$
	$v_L^H > \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-2}) q_O}$	$p_2^{Nu} = p_2^N = \frac{1-\delta^n}{1-\delta} v_L$	$\pi_{B7}^u = \frac{\delta(1-\delta^n)}{1-\delta} v_L$
<b>B8</b>	$v_L^H < \frac{1-\delta^n}{1-\delta^n - (1-\delta^{n-2}) q_O}$	$p_2^N = \frac{1-\delta^n}{1-\delta} v_L$	$\pi_{B8}^u = \delta \frac{1-\delta^n}{1-\delta} v_L d_L$

## Appendix 2

**Proof of Lemma 2.** In a partly-covered installed base, the utilities that the high and low types derive from purchasing the new product in period  $t$ ,  $t = 1, 2$ , are represented as  $U_{Nt}^H$  and  $Z_{Nt}^L$  respectively. By equations (2), (4), (5) and (6), we have:

(i).  $U_{Nt}^H > Z_{Nt}^L$  if and only if  $v_L^H > [1 - \delta^n] / \{1 - \delta^n - [1 - \delta^{n-t}] q_o\}$ ; otherwise  $U_{Nt}^H \leq Z_{Nt}^L$ .

(ii). When  $q_o \geq q_2$ ,  $\Delta Z_{Nt}^L / \Delta t < 0 \leq \Delta U_{Nt}^H / \Delta t$ .

(iii). When  $q_o < q_2$ ,  $\Delta U_{Nt}^H / \Delta t < \Delta Z_{Nt}^L / \Delta t < 0$  if and only if  $v_L^H > [1 - \delta^n] / [1 - \delta^n - q_o]$ ;

otherwise,  $\Delta Z_{Nt}^L / \Delta t \leq \Delta U_{Nt}^H / \Delta t < 0$ .  $\square$

**Proof of Lemma 3.** Referring to Table 4b, with strategy B3, the vendor only sells the new product in periods 1 and 2. The vendor extracts the full surplus from the low type in period 2 by charging price  $p_2^N = z_{o1}^L$ . Moving backwards, the price of the new product in period 1 is subject to self-selection, such that both consumer types would not deviate from the assigned purchase sequences:

$$U_{N1}^H - p_1^N \geq U_{N2}^H - \delta p_2^N \quad (A1)$$

$$Z_{N2}^L - \delta p_2^N \geq Z_{N1}^L - p_1^N \quad (A2)$$

Substituting (A1) and (A2) with  $p_2^N = z_{o1}^L$  results in the constraint for the price of the new product in period 1:

$$Z_{o1}^L - \Delta Z_{Nt}^L / \Delta t \leq p_1^N \leq Z_{o1}^L - \Delta U_{Nt}^H / \Delta t \quad (A3)$$

which is feasible if and only if  $\Delta U_{Nt}^H / \Delta t \leq \Delta Z_{Nt}^L / \Delta t < 0$ .

Referring to Table 6, only the region  $R(v_L^H > v_3, q_o \leq q_2)$  can satisfy this constraint.

The maximum price that the vendor can charge the high type in period 1 is:

$$p_1^N = Z_{o1}^L - \Delta U_{Nt}^H / \Delta t.$$

Similarly, for strategy B2, we get  $p_2^N = u_{N1}^L$ . In equilibrium, both types of consumers will follow the purchase sequences as outlined in Table 5b if they are unable to benefit more from the other alternative choices:

$$Z_{O1}^L + \delta U_{N1}^L - p_1^O - \delta p_2^N \geq Z_{O1}^L - p_1^O \quad (\text{A4})$$

$$Z_{O1}^L + \delta U_{N1}^L - p_1^O - \delta p_2^N \geq Z_{N1}^L - p_1^N \quad (\text{A5})$$

$$Z_{O1}^L + \delta U_{N1}^L - p_1^O - \delta p_2^N \geq Z_{N2}^L - \delta p_2^N \quad (\text{A6})$$

$$U_{N1}^H - p_1^N \geq U_{N2}^H - \delta p_2^N \quad (\text{A7})$$

Substituting  $p_2^N = u_{N1}^L$  into (A7) gives the maximum price that the vendor can charge the high type in period 1:

$$p_1^N = U_{N1}^H - (U_{N2}^H - \delta U_{N1}^L) = \delta U_{N1}^L - \Delta U_{Nt}^H / \Delta t ,$$

which is lower than the high type's incremental utility derived from the new product ( $U_{N1}^H$ ), and equals the discounted price charged to the low type in period 2 ( $\delta U_{N1}^L$ ) plus the relative benefit the high type gains from the early purchase ( $-\Delta U_{Nt}^H / \Delta t$ ). Thus,  $p_1^N$  is feasible if and only if  $\Delta U_{Nt}^H / \Delta t \leq 0$ , which corresponds to the region  $R(v_L^H, q_O \leq q_2)$  in Table 6. Similarly, substituting  $p_2^N = u_{N1}^L$  into (A4)-(A6), if  $v_L^H \leq v_3$ ,  $p_1^O = \delta U_{N1}^L - U_{N2}^H + U_{N1}^H + Z_{O1}^L - Z_{N1}^L$ ; otherwise  $p_1^O = \delta U_{N1}^L - Z_{N2}^L + Z_{O1}^L$ . []

**Proof of Lemma 4.** For strategy B4, the price of the new product in period 2 is  $p_2^N = u_{N2}^H$ .

The price ( $p_1^N$ ) in period 1 is subject to self-selection such that neither type are willing to deviate from the assigned purchase path:

$$Z_{N1}^L - p_1^N \geq Z_{N2}^L - \delta p_2^N \quad (\text{A8})$$

$$U_{N2}^H - \delta p_2^N \geq U_{N1}^H - p_1^N \quad (\text{A9})$$

Meanwhile,  $p_1^N$  is also subject to a participation constraint so that the low type's surplus from purchasing in period 1 is non-negative:

$$Z_{N1}^L - p_1^N \geq 0 \quad (\text{A10})$$

Substituting  $p_2^N = u_{N2}^H$  into (A6)-(A8) gives the constraint for the price of the new product in period 1:

$$U_{N1}^H \leq p_1^N \leq \min\{U_{N2}^H - \Delta Z_{N1}^L / \Delta t, Z_{N1}^L\} \quad (\text{A11})$$

which is feasible only in the region  $R(v_L^H \leq v_2, q_0)$  as shown in Table 6. Further,

$$\text{if } v_1 < v_L^H \leq v_2, p_1^N = Z_{N1}^L; \text{ otherwise } p_1^N = U_{N2}^H - \Delta Z_{N1}^L / \Delta t.$$

According to the above analysis, in the region  $R(v_1 < v_L^H \leq v_2, q_0)$ , the vendor can extract the full utility of the low and high types. The following proof shows that the low type, being aware of their zero surplus from purchasing in period 1, is unwilling to deviate.

Given  $v_1 < v_L^H \leq v_2$ , suppose there is an infinitesimal small group of low type consumers who delay their purchase of the new product to period 2. Denote the size of the deviating consumers as  $\gamma$ . Since  $p_2^N = u_{N2}^H$  is larger than  $z_{N2}^L$ , to capture the extra demand of the deviating consumers, the vendor has to reduce the price to be no higher than  $z_{N2}^L$ . Setting  $p_2^N = z_{N2}^L$ , the vendor's profit in the last period is  $\pi_{A4}^2 = z_{N2}^L \times (d_H + \gamma)$  which is less than  $u_{N2}^H \times d_H$  when  $\gamma \rightarrow 0$  with  $v_L^H > v_1$ . Consequently, even with an infinitesimal small group of low type consumers who reject the offer in period 1, the vendor would still not lower the price to their affordable level. Anticipating that they would not benefit from delayed purchase, no low type consumers would reject the offer in period 1. []

**Proof of Lemma 5.** As elaborated in footnote 9, the surplus of the low type consumers will be fully extracted if they only purchase the old product (i.e., strategy B6).

If the low type purchase the old and new products in periods 1 and 2 respectively, in the presence of an upgrade policy, the forthcoming new product would not cannibalize the

sales of the old product. Thus the vendor can charge the low type the full service value of the old product. In addition, the low type who have purchased the old product in period 1 have a lower reservation price for the new product than that of the high type ( $u_{N2}^H > u_{N1}^L$ ). Thus, the vendor can always extract the full surplus from the low type.

As for those strategies where the low type only purchases the new product in period 1 or 2 (i.e., B1, B3, B4, B7, B8), if the low type have a higher reservation price for the new product than the high type (e.g., when consumer heterogeneity is relatively low), the high type are willing to reveal their purchase history and obtain a discounted price for the new product. And the low type will be offered a higher price that equals their full utility derived from the new product. If the low type have a lower reservation price for the new product, of course, they will be left with zero surplus.

Thus, in any of the above cases, the surplus of the low type will be fully extracted. Following the same rationale, in the region where the low type have a higher reservation price for the new product (e.g.,  $R(v_L^H \leq v_2, q_o)$ ) or the region where the high type are better off from delayed purchase (e.g.,  $R(v_L^H, q_o > q_2)$ ), by offering an upgrade price, the vendor is still able to sell the new product to the high type in period 1 and to the low type in period 2. []