Delayed Product Introduction

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Abstract

We investigate the incentives of a monopolistic seller to delay the introduction of a new and improved version of his product. By analyzing a three-period model, we show that the seller may prefer to delay introducing a new product, even though the enabling technologies for the product are already available. The underlying motivation is analogous to that found in the durable goods monopolist literature – the seller suffers from a time inconsistency problem that causes his old and new products to cannibalize each other. Without the ability to remove existing stock of the old product from the market, shorten product durability, or pace research and development (R&D), he may respond by selling the new product later. We characterize the equilibria with delayed introduction, and study their changes with respect to market and product parameters. In particular, we show that delayed introduction could occur regardless of whether the seller can offer upgrade discounts to consumers, that instead, it is related to quality improvement brought about by the new product, durabilities, and discount factors. Further, we show that contrary to previous studies, delayed introduction could bring socially efficient outcomes as well. Based on the insights of the model, we provide practical suggestions on pricing and policies.

Key words: delayed introduction, durable goods monopolist, cannibalization, durability, time inconsistency, upgrade, product innovation, three-period model.

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1. Introduction

Technologies for wideband third-generation (3G) cellular networks and mobile phones have been available for several years, yet many telecommunications companies are still reluctant to provide 3G mobile phone services. The use of DVD media for recording, storing and retrieving voluminous data has been popular since the beginning of this century, but it was only recently that we started to see DVD video recorders being actively promoted by hardware vendors. The MP3 compression format for digital music has been well developed since the late 1990s, but it took several more years before we saw vendors of stereo systems include in their products MP3 decoders that read and playback MP3 files on CDs. Similarly, we have yet to see widespread use of the MPEG-4 standard in home electronic products, even though it became an international standard in the year 2000. Why do hardware vendors seem to hesitate in launching new and better products with cutting-edge technologies?

The examples above share a number of characteristics. First, the research and development (R&D) of the new technologies were often pioneered by independent researchers or companies, not by the hardware vendors who apply the technologies to their products. Therefore, the hardware vendors may not control when the new technologies become available. Second, many hardware vendors who consider using the new technologies sell products that incorporate previous generations of similar technologies. For example, most telecommunications companies currently provide mobile phone services on second-generation cellular networks and handsets; many vendors of DVD video recorders are also major sellers of conventional videotape recorders. Third, the markets for products that incorporate these new technologies, or earlier generations of similar technologies, tend to be concentrated – they are often dominated by a small number of large sellers. Fourth, products that use these (new or earlier-generation) technologies are mostly durable. They supply long streams of services to consumers, and the quality of services does not significantly drop over time. Hence, consumers often take into account the durability of such products when making purchase decisions. Finally, the functional values of products that use earlier-generation technologies are not affected by the presence of products with the new technologies. If consumers do not appreciate the new technologies, they can ignore the new products and continue using the products they have purchased.

Given these common characteristics and the intriguing observation that some sellers seem reluctant to launch new products that incorporate better technologies, it is interesting to understand the strategic decisions of a seller who currently sells an existing product, and who can choose whether to sell a new product with better technologies. Specifically, we address the following research questions: Suppose a new technology that improves the quality of an existing product is introduced, and applying it to a new product does not involve prohibitively high costs. Would a seller have the incentives to deliberately delay selling the new product? If so, under what circumstances would the seller adopt such a strategy?

We use a stylized economic model which closely follows the spirit of the classical durable goods monopolist literature[1] to answer the above research questions. Our model consists of three periods, and each period comprises two stages. In the first stage of each period, a monopolistic seller makes product and pricing decisions. In the second stage, consumers observe the offers made by the seller and decide whether to buy the product. The seller can only sell a low-quality product in the first period. In the second period, owing to external R&D, a new technology arrives that enables him to produce and sell a high-quality product. The seller has to choose among three courses of action: (a) sell the high-quality product immediately in the second period; (b) sell the high-quality product in the third period; or (c) do not sell the high-quality product in either period. Option (b) corresponds to delayed introduction – the seller purposely chooses not to sell a better product in an earlier period, even though the product is available and he could feasibly sell it to consumers. We further allow the low- and high-quality products to exhibit various degrees of durability. This facilitates generalizations of our findings to different technological products. The chosen market structure and model features resemble the characteristics of the examples that we have raised (3G mobile phone services, DVD video recorders, etc.).

In our model, we find that under a wide range of conditions, the seller has incentives not to sell the new (high-quality) product immediately. This is because the existing stock of the old (low-quality) product that has been sold to consumers limits his ability to charge a high price for the new product (i.e., the old product cannibalizes the new product). Further, the expectation that there is going to be a new product in the future may dampen the incentives of consumers to buy the old product. Unless the price of the old product is low, consumers may prefer to wait and buy the new product that promises better quality (i.e., the prospect of a new

[1] Representative works in this literature include Bulow (1982, 1986), Dhebar (1994), Fishman and Rob (2000), Fudenberg and Tirole (1998), Kornish (2001), Lee and Lee (1998), Levinthal and Purohit (1989), Purohit (1994), Stokey (1981), and Waldman (1993, 1996a, 1996b). For an excellent summary, see Waldman (2003).

product in the future also cannibalizes the old product). It is these intertemporal cannibalizations between the old and new products that lead the seller to delay selling the new product.

Specifically, by deferring sale of the new product, the seller extends the economic life span of the old product, which increases its value to consumers. It also allows the old product to be used for one more period, and hence the old product depreciates more in value; consumers who have bought it in an earlier period would then be willing to pay more to upgrade to the new product in a later period. This allows the seller to charge a higher price for the new product and earn more profit.[2]

To provide useful strategic insights, we analyze our model in two separate scenarios. In the first scenario, the seller cannot implement an upgrade policy. Hence, all consumers must pay the same price to acquire the new product. In the second scenario, the seller can implement an upgrade policy that allows consumers to trade in the old product for the new product at a discounted price. Compared with other consumers, those who own the old product pay less to enjoy the new product (in other words, the seller can practice price discrimination based on the purchase history of consumers).

We find that the seller chooses different product and pricing strategies in these two scenarios. Generally, he prefers the upgrade policy because it allows him to convince all consumers to purchase the old product as soon as possible. The provision of an upgrade option also leads to socially efficient outcomes.

Regardless of whether the seller can implement an upgrade policy, however, delayed selling of the new product is always optimal for the seller with some combinations of product and consumer characteristics. Therefore, the provision of an upgrade policy may not be the key determinant in the introduction timing of next-generation technological products (cf. Fishman and Rob 2000). Instead, we find that the seller's choice of whether to delay selling the new product is related to product durabilities, extent of quality improvement, and the discount factors.

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[2] In practice, when deciding whether to upgrade a technological product (e.g., personal computer), consumers often need to assess the remaining service values of their existing products. If the existing products are expected to have short life spans, consumers may be willing to pay more to upgrade to new products.

Our study provides useful insights for managers of technological products, especially those that depend heavily on components developed by external vendors. Popular examples of such products include personal computers, audio-visual equipment, communication tools, and specialized software (e.g., econometrics or statistics software). For vendors of these products, delaying the sales of new products that use better technologies may sometimes be beneficial because of the alleviation of intertemporal cannibalizations. Further, if a vendor is hesitant about when to sell a new product, our model suggests that he should evaluate the durabilities of his products and the improvement in quality that the new product will bring to consumers. Knowledge of whether consumers are patient is also useful in this context.

The remainder of this paper is organized as follows. Section 2 reviews previous research that is related to delayed introduction of new products. Section 3 presents our research model. Section 4 outlines the analysis and characterizes all equilibria in the studied markets. Section 5 relaxes a few assumptions of the model, and explores how they affect the analytical outcomes. Section 6 concludes the paper.

2. Related Works

The literature on technology diffusion, adoption and strategic management has suggested that fear of obsolescence may cause consumers to hesitate or refuse to buy current technological products (Cohen et al. 1996; Dhebar 1996; Venkatesh and Brown 2001). The concern of consumers about product obsolescence is particularly noteworthy in high technology markets because the usability (or durability) of such products is often governed by external technological progress, standards or architectures (Morris and Ferguson 1993; West and Jason 2000). Evidently, hardware products suffer from wear and tear, and sometimes, changes in communications standards with peripheral technologies.[3] Even software products that are supposedly perfectly durable could at times be superseded because of updates in processor instruction sets or operating systems. Therefore, to avoid getting products that could soon be obsolete, consumers may wait for new products and defer making purchases – this is often called leapfrogging in the literature.

[3] For example, the growing popularity of the universal serial bus (USB) interface has rendered many computer peripherals that use old communication interfaces, such as parallel or serial ports, obsolete. Similarly, rapid changes in processor and mother board architectures have made old-generation random access memory (RAM) chips incompatible with new PCs.

In response to the threat of leapfrogging by consumers, firms that sell multiple generations of similar products may wish to slow down the pace of new product introduction. This could serve two purposes. First, delayed introduction may help dissuade consumers from waiting for new products and accumulate potential buyers for future products (Putsis 1993). Second, it may lessen the regret of consumers who have bought old-generation products and persuade them to switch to new products in the future (Dhebar 1996).

Various theoretical studies have responded to the above observations and modeled the timing decisions of firms that sell multiple generations of similar products. Specifically, by studying the decisions of a monopolist in a two-period framework, Dhebar (1994) and Kornish (2001) conclude that a seller may defer selling new products because if product introduction occurs too frequently, it is difficult to make all products appear attractive to consumers. They have not, however, formally characterized any equilibrium that involves delayed introduction of new products. Chatterjee and Sugita (1990) and Radas and Shugan (1998) show that delayed introduction is optimal when demand is uncertain, or when demand is seasonal and expanding. Their results stem from specific assumptions on demand structures and firms' knowledge. By contrast, we show that even if demand is constant and a seller has perfect knowledge about consumers, delay is still an optimal strategy in many circumstances.

Our study is perhaps closest to that of Fishman and Rob's (2000), which illustrates that in a continuous-time framework with homogeneous consumers, no upgrade policies, and perfectly durable products, a monopolist's rate of product innovation would be too low, which could cause inefficient delays in new product introductions. They show that with an upgrade policy, however, the seller would not delay new product introductions,[4] which is different from what we report in this paper. Our setting differs from that of Fishman and Rob's in three aspects. First, in their setting, product innovation involves R&D costs, and new products are launched as soon as they become available. Hence, their concept of delay is that of innovation, not of introduction per se. In our case, product innovation is exogenous and fixed; we focus on the seller's strategic choice of when to sell a new product that has just become available – a decision that follows product innovation and does not involve R&D costs. Second, they consider only perfectly durable products. By contrast, we include durability as a model parameter, and that allows us to extend our insights to different technological products,

[4] Lee and Lee (1998) derive similar conclusions in a two-period model with two groups of consumers.

especially those that work closely with base products (as in computer software and hardware) or peripheral components (see footnote 3 and the related discussion above). Third, they do not explicitly demonstrate that the seller would prefer a strategy with delayed product introduction. By contrast, we illustrate through comprehensive evaluations of possible strategies that under a wide range of conditions, the seller would prefer delayed introduction owing to revenue but not cost considerations.

3. The Model

Consider a monopolistic seller who is planning to sell two versions of a product over three periods, $t = 1, 2$ or 3. In period 1, he can only sell a low-quality product, L, with quality q_L. Owing to R&D, a new technology arrives in period 2, which allows him to sell a new product, H, with quality $q_H > q_L$, in either period 2 or 3. For ease of presentation, we normalize q_H to one, and hence $0 < q_L < q_H = 1$. Both the old (low-quality) and new (high-quality) products are of the same durability $n \geq 2$ periods. We shall relax this assumption and allow for different durabilities later in Section 5. We further assume zero fixed and marginal costs to focus on the strategic choices of the seller in response to market demand.[5]

On the demand side, consumers are homogeneous, and we normalize their size and valuation for quality to one. Each consumer demands at most one unit of each version of the product. Within its life span, the product provides a constant stream of services 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 δ to denote a discount factor, which is common to both seller and consumers. We shall relax this assumption in Section 5. Note that $0 \leq \delta \leq 1$. The larger δ is, the smaller the discount in future utilities or prices will be.

Each period in the model further consists of two stages. In the first stage, the seller makes product and pricing decisions based on his knowledge of consumer profiles (how many people bought the products in previous periods, the utilities they derive from the products, etc.). In the second stage, consumers make purchase decisions, taking into account their

[5] We shall discuss the implications of positive marginal costs in Section 5.

valuations for 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 seller and consumers is available. We focus on rational expectations equilibria in which consumers form expectations about the product and pricing decisions of the seller, and the seller fulfills such expectations.

We use a tuple {·, ·, ·} to represent the product strategies of the seller in the three periods. For example, {*L*, -, *H*} indicates that the seller sells the old product in the first period, does not sell any product in the second period, and sells the new product in the third period. Similarly, {*L*, *H*, -} denotes a similar strategy except that the new product is sold in the second period instead of the third. Because consumers have identical valuations for products, the seller would sell only one product in each period. Further, once a product is sold in a period, it would not be sold in subsequent periods.[6]

For each product strategy, the seller needs to devise a price schedule. An equilibrium is sub-game perfect if the seller receives optimal profit from his product and price schedules, and if the schedules are consistent with consumer expectations. We use p_t^i to denote the price of product *i* at time *t*, where *i* = *L*, *H* and *t* = 1, 2, or 3, and p_t^{Hu} to denote the upgrade price of product *H* at time *t*, where *t* = 2 or 3 (upgrade price is necessary only for the new product, and the new product can only be sold at or after period 2).

Given this setting, there are eight possible product strategies for the seller, which are listed in the first column of Table 1. Our analysis proceeds as follows. For each product strategy, we calculate the total utility that consumers can enjoy from using the sequence of products. For example, consider the strategy {*L*, -, -}, where the seller only sells the old product in the first period. Consumers can enjoy a utility of q_L in the first period, δq_L in the second period, $\delta^2 q_L$ in the third period, and so on, until $\delta^{n-1} q_L$ in the last period of the usable life span of the product. Summing these values, the total utility that a consumer can enjoy,

$$u_{\{L,-,-\}} = \left[\frac{1-\delta^n}{1-\delta}\right] q_L .$$

[6] In a model where consumers have different valuations for products, or where new consumers enter the market in subsequent periods, it is possible for a seller to sell both old and new products in the same period, and he may also sell the same products over time.

The utilities that consumers can enjoy from other product strategies are calculated in a similar manner. These are all listed in the second column of Table 1.

<Insert Table 1 here>

Then, based on the utility that consumers derive from each strategy, we compute an optimal price schedule and the associated profit that the seller can make by choosing such a strategy. Finally, the profits are compared across the eight product strategies to determine the optimal choices of the seller. We then characterize a few necessary and sufficient conditions that lead to equilibria with delayed selling of the new product.

4. Analysis

When setting prices, the seller has to consider consumer expectations and their possessions of products. In particular, consumers would buy or upgrade to a new product if and only if the total surplus that they derive from the purchase or upgrade is positive (participation constraint) and is more than those from any other options (self-selection constraint). Further, consumers expect new products to be available in the future. Therefore, before they make a purchase, they would compare its prospect with that of waiting for a new product. It is these considerations about consumer actions that limit the flexibility of pricing for the seller.

We separate our analysis into two scenarios. In the first scenario, the seller cannot provide an upgrade option to consumers; hence, all consumers pay the same price for the new product. In the second scenario, the seller can devise an upgrade policy, which allows consumers to trade in the old product for the new product at a discounted price.

4.1 With No Upgrade Policies

When the seller cannot identify consumers who have previously bought his product, or when the administrative cost of trade-in is too high, it is infeasible for him to offer an upgrade discount to consumers. All consumers must then pay the same price for the new product, which means that $p_2^{Hu} = p_2^H$ and $p_3^{Hu} = p_3^H$.

Given the product strategies in Table 1, it is easy to calculate the price schedules and profits of the seller. For illustrative purpose, we present the results with respect to strategies {*L*, -, -}

and {L, H, -} below. The price schedules and profits of other strategies can be computed by following similar procedures.

In strategy {L, -, -}, the seller only sells the old product in period 1. His problem is:

$$\max_{p_1^L} \pi_{\{L,-,-\}} = p_1^L ,$$

$$\text{s.t.} \quad \left[\frac{1-\delta^n}{1-\delta}\right] q_L - p_1^L \geq 0 . \tag{1}$$

The left-hand side of (1) is the net surplus that consumers can enjoy by buying the product. Essentially, (1) is a participation constraint that ensures that consumers buy the old product in the first period. Solving the above problem, we have:

$$p_1^L = \pi_{\{L,-,-\}} = \left[\frac{1-\delta^n}{1-\delta}\right] q_L .$$

In strategy {L, H, -}, the seller sells the old and new products in the first and second periods. He has to set two prices: the price of the old product in period 1, p_1^L, and the price of the new product in period 2, p_2^H. His profit maximization problem is then:

$$\max_{p_1^L,\, p_2^H} \pi_{\{L,H,-\}} = p_1^L + \delta p_2^H ,$$

$$\text{s.t.} \quad \left[\frac{1-\delta^n}{1-\delta}\right] q_L - p_1^L + \delta \left\{ \left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right] q_L - p_2^H \right\} \geq 0 , \tag{2}$$

$$\left[\frac{1-\delta^n}{1-\delta}\right] q_L - p_1^L + \delta \left\{ \left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right] q_L - p_2^H \right\} \geq \left[\frac{1-\delta^n}{1-\delta}\right] q_L - p_1^L , \tag{3}$$

$$\text{and} \quad \left[\frac{1-\delta^n}{1-\delta}\right] q_L - p_1^L + \delta \left\{ \left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right] q_L - p_2^H \right\} \geq \delta \left\{ \left[\frac{1-\delta^n}{1-\delta}\right] - p_2^H \right\} . \tag{4}$$

The left-hand side of (2)-(4) is the net surplus that consumers enjoy by buying both products. Similar to (1), (2) is a participation constraint. Both (3) and (4) are self-selection constraints; (3) prevents consumers from buying only the old product whereas (4) prevents them from skipping the old product and buying only the new one. Rearranging the terms, (3) and (4) can be simplified as:

$$p_2^H \leq \left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right] q_L , \tag{5}$$

and

$$p_1^L \leq q_L . \tag{6}$$

(5) imposes a constraint on the feasible price of the new product. Because the existing stock of the old product continues to provide service if consumers do not buy the new product, the seller could only charge consumers for the *incremental* value the new product brings. Further, (6) says that the price of the old product is bound too because expectations of future switch to the new product reduces the life span of and hence the price that consumers are willing to pay for the old product. Essentially, (5) and (6) imply that if the seller wants consumers to buy the new product but cannot offer an upgrade discount to existing customers, then he has to absorb the wastage associated with scrapping the old product prematurely (i.e., before the end of its physical life span).[7]

Solving the seller's problem subject to (2), (5) and (6), the optimal prices and profits are:

$$p_1^L = q_L , \; p_2^H = \left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right] q_L ,$$

and

$$\pi_{\{L,H,-\}} = q_L + \delta \left\{ \left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right] q_L \right\} .$$

Note that $\pi_{\{L,H,-\}} < u_{\{L,H,-\}}$. That is, if the seller chooses to sell two products, then he has to leave consumers with positive surplus – the service values of the old product from the second period onwards would have to be a give-away to consumers. This is always true whenever the two products are sold in the planning horizon and the seller cannot implement an upgrade policy. The price schedules of all product strategies and the associated profits for the seller are reported in the third and fourth columns of Table 1.

By inspecting the seller's profits, we see that strategy {*L*, -, -} dominates strategies {-, *L*, -} and {-, -, *L*}; strategy {*L*, *H*, -} dominates strategy {-, *L*, *H*}; and strategy {-, *H*, -} dominates strategy {-, -, *H*}. That is, the seller would not postpone selling the same sequences of products. The only remaining strategies are {*L*, -, -}, {*L*, *H*, -}, {*L*, -, *H*}, and {-, *H*, -}. Comparing the seller's profits across these four strategies, our first set of results follows. The proofs of all propositions and corollaries are available in the Appendix.

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7 Fishman and Rob (2000) make a similar observation in their study of new product introductions.

Proposition 1 [Optimal product strategies with no upgrade policies]:

Suppose that the seller cannot implement an upgrade policy.[8]

- [*Status quo*]: Strategy {*L*, -, -} is optimal if and only if $q_L > \delta$ and $q_L > \frac{1-\delta^n}{2[1-\delta^{n-2}]}$.
- [*Leapfrogging*]: Strategy {-, *H*, -} is optimal if and only if $q_L < \delta$,

  $q_L < \frac{\delta[1-\delta][1-\delta^n]}{1-2\delta^2+\delta^n}$, and $1-2\delta+\delta^n < 0$.
- [*Immediate sale*]: Strategy {*L*, *H*, -} is optimal if and only if $q_L < \frac{1-\delta^n}{2}$ and

  $1-2\delta+\delta^n > 0$.
- [*Delayed introduction*]: Strategy {*L*, -, *H*} is optimal if and only if $q_L > \frac{1-\delta^n}{2}$,

  $q_L > \frac{\delta[1-\delta][1-\delta^n]}{1-2\delta^2+\delta^n}$ and $q_L < \frac{1-\delta^n}{2[1-\delta^{n-2}]}$.

Corollary: As durability, *n*, increases, the necessary and sufficient conditions for *delayed introduction* become stronger. When $n \to \infty$, the *delayed introduction* strategy, {*L*, -, *H*}, is always dominated by one of the other three strategies.

Figure 1 plots the ranges of parameters for each of the above strategies to be optimal under various durabilities. Generally, three parameters characterize the incentives of the seller to delay selling the new product: quality of the old product, q_L (since we have normalized q_H to one, q_L also represents the degree of product improvement brought by the new technology; the smaller q_L is, the larger the quality improvement will be), product durability, *n*, and discount factor, *δ*. As Figure 1 clearly shows, the region for *delayed introduction* gradually shrinks as *n* increases, and is negligible when *n* is sufficiently large (say, $n \geq 10$).

<Insert Figure 1 here>

By the self-selection constraint (3) and hence the price constraint (5), it is clear that the existing stock of the old product imposes a negative externality on the new product. Specifically, (5) limits the maximum price, which is dependent on the difference in service

[8] For brevity, we assume that the constraints are not binding. If any one of the constraints is binding, then the seller may choose more than one strategy with equal probability.

values provided by the two products at the time of evaluation, that consumers are willing to pay for the new product. In strategy {*L*, -, *H*}, the old product is used in both periods 1 and 2. Therefore, its residual value in period 3 is lower than that in period 2 in strategy {*L*, *H*, -}. The seller could then charge a higher price and earn more revenue for the new product. This is confirmed by the fact that $p_3^H > p_2^H$ in strategies {*L*, -, *H*} and {*L*, *H*, -}.

Further, by (4) and hence (6), the new product also imposes a negative externality on the old product. This is because consumers expect to buy the new product and scrap the old product in the near future. Hence, they are willing to pay *only* for periods in which the old product is in service (i.e., the new product causes premature obsolescence of the old product). The longer consumers expect to use the old product, the more they are willing to pay for it. Provided that the expected usage of the old product is less than its physical life span, however, its price would fall short of what it should deserve. The seller then has to subsidize consumers if he wants them to buy the new product before the old product becomes dysfunctional.

Therefore, the seller has to face mutual cannibalizations between the old and new products if he wants to sell both of them in the planning horizon. To alleviate such cannibalizations, the seller could either push back the selling of the new product, or remove the old product from the market. The former action could lead to delayed appearance or even shelving of the new product. The latter action could result in leapfrogging by the seller, and only the new product would be sold in the second period; consumers would not be able to use the old product in the first period. By Proposition 1, all of these outcomes are possible in equilibrium.

If the seller decides to sell both products but postpones sale of the new product to the last period, then two opposite forces would be in contention. First, he would collect revenue from the new product at a later period, which tends to act against delay. Second, additional depreciation of the old product allows him to charge a higher price for the new product (i.e., the extent of cannibalization is now smaller). Also, because the old product is used for an extended period, the seller could charge a higher price for it too. These price effects tend to favor delay. Whether delayed introduction is optimal largely depends on the balance of these two opposite forces.

When the discount factor, δ, is large (i.e., the discount of future values is small, or equivalently, the seller and consumers are patient), the first force above, owing to delayed revenue from the new product, becomes insignificant, and it may suggest that the seller would prefer the *delayed introduction* strategy; this is indeed consistent with the findings of Kornish (2001) and Radas and Shugan (1998). Interestingly, this is not always the case in our setting because besides the two full product line strategies, {*L*, *H*, -} and {*L*, -, *H*}, the seller may also choose to shelf either the old or new product – after all, this is the most effective way to completely resolve the cannibalizations between the products. In general, low quality improvement tends to raise the attractiveness of the *status quo* strategy, {*L*, -, -}, and high quality improvement, together with a high discount factor, tends to raise the attractiveness of *leapfrogging*, {-, *H*, -}. Delaying sale of the new product within the planning horizon does not necessarily follow a high discount factor.[9]

By contrast, we find that durability, n, and product improvement, q_L, are stronger predictors of delayed introduction. In particular, if both products are durable, and if the new product is somewhat better than the old one, then the gain brought by lower cannibalization (the second force above) is minor. The new product prices with and without delay, p_3^H for {*L*, -, *H*} and p_2^H for {*L*, *H*, -}, are large but similar, however, and hence the loss associated with deferral of revenue from selling the new product is big. The seller would then prefer to sell the new product as soon as possible, i.e., strategy {*L*, *H*, -} is optimal.

Proposition 1 characterizes the conditions – low durability and incremental (but not radical) quality improvement – for delayed introduction of new products. These conditions seem to match the features of many high technology products, such as MP3-compatible home stereo systems or DVD video recorders, and hence, may explain why their sellers often launch new products later, even though the enabling advanced technologies are already available.

4.2 With an Upgrade Policy

We now consider the case when a seller can implement an upgrade policy. The provision of the upgrade option is an extra instrument for a seller to exercise price discrimination based on

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[9] Kornish (2001) and Radas and Shugan (1998) do not consider the possibility of selling only one product in the planning horizon. Therefore, their conclusion that the choice of delay is tied to the discount factor is not generalizable to other product line strategies. As we shall illustrate below, however, the role of the discount factor in predicting delay is significant when the seller can implement an upgrade policy.

purchase history (Fudenberg and Tirole 1998; Lee and Lee 1998). If the seller can identify consumers who have bought the old product, he can charge them for only the incremental utility that they receive by using the new product. For those who do not own the old product, he can charge them for the full utility. In our setting, because all consumers are identical, they exhibit the same behavior in equilibrium. Nevertheless, upgrade is relevant because the seller can now make a credible threat that if the consumers do not buy the old product in the first period, they will face a very high price for the new product in subsequent periods (cf. those who trade in the old product for the new product). This threat of price discrimination dissuades consumers from leapfrogging and encourages them to buy the old product as soon as it is available for sale.

The analyses with an upgrade policy resemble those that we have presented above; in the five product strategies with single products, the price schedules and profits are identical to the previous case with no upgrade policies. The prices and the seller's profits in strategies {*L*, *H*, -}, {*L*, -, *H*} and {-, *L*, *H*}, however, differ from those we have obtained above. For illustrative purpose, we present the results with respect to strategy {*L*, *H*, -} below.

In strategy {*L*, *H*, -}, the seller needs to set three prices: the price of the old product in period 1, p_1^L, the price of the new product in period 2, p_2^H, and the *upgrade* price of the new product in period 2, p_2^{Hu}.[10] The seller's profit maximization problem is then:

$$\max_{p_1^L,\, p_2^{Hu}} \pi_{\{L,H,-\}} = p_1^L + \delta p_2^{Hu},$$

s.t.
$$\left[\frac{1-\delta^n}{1-\delta}\right]q_L - p_1^L + \delta\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right]q_L - p_2^{Hu}\right\} \geq 0, \tag{7}$$

$$\left[\frac{1-\delta^n}{1-\delta}\right]q_L - p_1^L + \delta\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right]q_L - p_2^{Hu}\right\} \geq \left[\frac{1-\delta^n}{1-\delta}\right]q_L - p_1^L, \tag{8}$$

and
$$\left[\frac{1-\delta^n}{1-\delta}\right]q_L - p_1^L + \delta\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right]q_L - p_2^{Hu}\right\} \geq \delta\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - p_2^H\right\}. \tag{9}$$

The left-hand side of (7)-(9) is the net surplus that consumers enjoy by buying the old product in period 1 and upgrading to the new product in period 2. Similar to (1), (7) is a participation

[10] The seller needs to specify the new product price in period 2 to prevent consumers from leapfrogging. As we shall show below, he makes more profits by selling the two products sequentially (offering an upgrade discount to those who own the old product) than by only selling the new product in period 2.

constraint. (8) is a self-selection constraint that restricts the upgrade price, and (9) is the constraint that ensures consumers do not leapfrog by skipping the old product. Solving the profit maximization problem, the optimal prices and profit are:

$$p_1^L = \left[\frac{1-\delta^n}{1-\delta}\right]q_L,\ p_2^{Hu} = \left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right]q_L,\ p_2^H > \left[\frac{1-\delta^n}{1-\delta}\right],$$

and

$$\pi_{\{L,H,-\}} = \left[\frac{1-\delta^n}{1-\delta}\right]q_L + \delta\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right]q_L\right\} = q_L + \delta\left[\frac{1-\delta^n}{1-\delta}\right].$$

Note that $\pi_{\{L,H,-\}} = u_{\{L,H,-\}}$. That is, the seller can extract all surplus from consumers. This result holds whenever the seller can implement an upgrade policy. The price schedules of all product strategies are reported in the fifth column of Table 1. With an upgrade policy, the profits of the seller always equal the consumer utilities that are reported in the second column of Table 1.

Similar to the case with no upgrade policies, the seller does not delay selling the same sequences of products. With an upgrade policy, strategy {*L*, *H*, -} further dominates strategies {*L*, -, -} and {-, *H*, -}. The only remaining strategies are the two with full product lines, {*L*, *H*, -} and {*L*, -, *H*}. Comparing the seller's profits, our second proposition follows.

Proposition 2 [Optimal product strategies with an upgrade policy]:

Suppose that the seller can implement an upgrade policy.

- [*Immediate sale*]: Strategy {*L*, *H*, -} is optimal if and only if $q_L < 1-\delta^n$.
- [*Delayed Introduction*]: Strategy {*L*, -, *H*} is optimal if and only if $q_L > 1-\delta^n$.

Corollary: As *n* increases or δ decreases, the necessary and sufficient condition for *delayed introduction* becomes stronger. When $n \to \infty$ or $\delta \to 0$, *delayed introduction* is not optimal; the seller would always sell the new product as soon as it is available.

Figure 2 depicts the condition in Proposition 2. The implications of Proposition 2 are similar to those of Proposition 1, except that the discount factor now plays a more important role. The interpretations are straightforward – if quality improvement is low, the discount factor is large, or durability is low, then delayed selling of the new product is more likely; otherwise, the seller would launch the new product immediately. The intuitions of these findings follow directly from those that we have presented in the previous section.

<Insert Figure 2 here>

Note the old product's prices in period 1 in Table 1 – they are much higher than those in the case when the seller cannot implement an upgrade policy. Recall that if the seller sells both products, then the new product may cause premature obsolescence of the old product because the latter is scrapped before the end of its physical life span. The provision of an upgrade policy could internalize such an externality because even though the old product is retired before the end of its physical life span, it allows its owner to buy the new product at a discounted price. Therefore, the old product provides a higher value (cf. that in the no upgrade case) to consumers, and the seller can now charge for its full value. It is also because of this trade-in value of the old product that the seller does not prefer the single-product strategies – he could always capture all consumer surplus associated with using the products, which is bigger than that in the single-product strategies {*L*, -, -} and {-, *H*, -}.

Finally, with an upgrade policy, the seller's choices in equilibria are socially efficient, including those that involve delayed introductions. This is because if the new product is launched too early, the old product, which could still provide useful service to consumers, would be retired prematurely. This means that useful resources are wasted, which causes inefficiency in welfare.[11] Note further that efficient outcomes are not guaranteed when an upgrade policy is not feasible because the seller's desperate effort to resolve the two-way cannibalizations between his products may cause him to drift away from socially optimal actions.

5. Extensions

In this section, we relax a few assumptions that we have made in the above analyses. First, we allow the old and new products to be of different durabilities and study how the seller's choice of strategies changes when the relative durability of the products varies.

[11] Although with *delayed introduction* consumers cannot use the new product immediately, they can extend usage of the products into a more distant future. Specifically, they can use the (old and new) products for $n + 2$ periods with strategy {*L*, -, *H*}, but only $n + 1$ periods with strategy {*L*, *H*, -}.

Generally, a more durable product provides a longer stream of services to consumers, who would then be willing to pay more for the product. If the durability of the new product, n_H, is high relative to that of the old product, n_L, then the total utility that consumers enjoy by buying or upgrading to the new product, and hence the prices that the seller could charge for it, becomes a more important decision factor. If the new product is sold later, the loss in revenue because of the discount factor is significant. The intertemporal cannibalizations between the products are not affected, however, by the durability of the new product. Hence, ceteris paribus, increases in n_H relative to n_L would entice the seller to sell the new product earlier, or, if originally he preferred the *status quo* strategy (in the scenario with no upgrade policies), to reconsider introducing the new product within the planning horizon.

By contrast, if n_H decreases relative to n_L, the loss in revenue for selling the new product later is lower because now the new product is worth less to consumers. Cannibalization rises to become a potent threat, and as a result, the seller would more likely postpone sale of the new product. In the extreme case where the new product has a substantially shorter life span than the old product, the seller may even decide not to sell the new product in the planning horizon. We summarize these intuitions in the following proposition.

Proposition 3 [Change in durabilities]:

Suppose that n_H increases relative to n_L.

- The necessary and sufficient conditions for the *status quo* and *delayed introduction* strategies, {L, -, -} and {L, -, H}, become stronger. The seller is less likely to shelf or delay sale of the new product.
- If the seller originally chose not to sell the new product, it is now possible for him to re-introduce it in the planning horizon and sell it in the last period.

The opposite is true if n_H decreases relative to n_L. If $n_H < n_L - 2$, it is possible for the seller to shelf the new product (i.e., choose the *status quo* strategy) even though he is able to devise an upgrade policy.

Figure 3 shows the changes in the feasible region of each product strategy when the durability of the new product changes relative to that of the old product.

<Insert Figure 3 here>

We next consider the case where the seller and consumers have different discount factors. Let the discount factor of the seller be θ and that of consumers be δ. Intuitively, one might think that a less patient seller (i.e., θ is smaller) would sell the new product as soon as possible to capture a higher discounted revenue. This conjecture is indeed correct if the seller can implement an upgrade policy. Interestingly, if an upgrade policy is not viable, a decrease in θ may induce the seller to shelf the new product even though he might have originally planned to sell it. This is because the new product reduces the price that he could charge for the old product in the first period, which is now more important owing to a higher discount of future revenue.

Recall that with an upgrade policy, the seller could internalize the cannibalization caused by the new product, and could always charge the full price for the old product. Hence the change in the discount factor only affects the *incremental* revenue that he receives from those who upgrade to the new product. A lower discount factor (i.e., a higher discount of future revenue) would naturally prompt him to launch the new product earlier.

By contrast, with no upgrade policies, the reverse cannibalization from the new product to the old one is significant. The seller then has to balance carefully the gain from launching the new product in the future against the loss in first period revenue from the old product. If he is less patient (i.e., when θ decreases), his concern about the old product's price is higher than that about the new product's price. Hence, he has a higher tendency to shelf the new product and a lower tendency to leapfrog. The choice of *delayed introduction* against *immediate sale* and *leapfrogging* is, however, ambiguous.[12] We summarize these results in the following proposition.

Proposition 4 [Change in discount factors]:

Suppose that the seller's discount factor, θ, decreases relative to that of the consumers, δ.

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[12] The seller's revenue from selling the new product in *delayed introduction* involves a second-order discount, which reduces his revenue rapidly as θ decreases. Further, in the *delayed introduction* strategy, his revenue from selling the old product is also a function of the consumers' discount factor, δ. The effect of a change in θ relative to δ depends on their relative magnitude. If θ is large, decreases in θ would make the new product substantially less attractive; hence, delay is less appealing to the seller. By contrast, if θ is small, a further decrease does not make much difference, and delay could be preferred because it increases the old product's price. Therefore, the seller does not unequivocally prefer or avoid *delayed introduction* (cf. *immediate sale* and *leapfrogging*).

- With no upgrade policies, the necessary and sufficient conditions for *status quo* become weaker. The seller has a higher tendency to shelf the new product. His choice over the other three product strategies is ambiguous.
- With an upgrade policy, the sufficient condition for *delayed introduction* becomes stronger. The seller has a higher tendency to sell the new product earlier.

Figure 4 shows the changes in the feasible region of each product strategy when the discount factor of the seller decreases relative to that of the consumers.

<Insert Figure 4 here>

Finally, we assume zero marginal costs for both the old and new products. If marginal cost is positive and correlates with product quality, its impact on the seller's product strategies is straightforward: if cost increases with quality, then selling the new product is less attractive to the seller (cf. the case that we have analyzed in Section 4), and he may delay its sale or shelf it. The opposite is true if cost decreases with quality – he may launch it earlier, or in the extreme case, leapfrog and skip the old product. What is more interesting here is that a high marginal cost for the new product may make upgrade less lucrative for the seller because other than participation and self-selection constraints, there is an additional cost constraint in the seller's maximization problem that places a lower bound on the upgrade price that is set by the seller. An immediate conjecture is that the conditions for the seller to provide upgrade discounts to existing customers would become more stringent, and he would more likely choose product strategies that involve selling only one product in the planning horizon. To prove this result, however, we need a more general model with various marginal costs and endogenous choices of upgrade policies. We leave this problem to future research.

6. Concluding Remarks

Using a three-period model, we have shown that a monopolistic seller would at times prefer to delay introducing a new product, even if technologies for the product are already developed and it is costless to sell it to consumers. This is because the old and new products affect each other adversely, which is similar to cannibalizations in standard product differentiation studies (e.g., Moorthy 1984; Mussa and Rosen 1978). In the product differentiation literature, the seller mitigates cannibalizations by dispersing his products; in our setting, he postpones selling the new product. We have characterized a few equilibria with delayed introduction of the new product, and studied their changes with respect to market and product parameters.

The findings of our study are relevant to high-technology products because their quality and life spans are increasingly being determined by external forces, such as developments in peripheral components, communications standards, or hardware and software architectures. In particular, sellers of these products often cannot control when new technologies arrive and when their old products 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 whether and when to sell new products. Because of this separation of sale from innovation, we find that in social optimum, a seller may defer introducing a new product; this is an insight that cannot be obtained in prior studies of product introduction (Fishman and Rob 2000; Lee and Lee 1998; Waldman 1996a).[13] It also explains why in some markets, sellers do not deploy new and superior technologies to create new products. The inclusion of durability as a model parameter also allows us to extend our insights directly to products that exhibit different life spans (perhaps because of high dependencies on external parts, technologies, or trends).

Our findings provide interesting insights for pricing and policy formulations. First, uniform pricing of new products is not desirable – a seller should seek to provide upgrade discounts to existing customers whenever feasible. Second, if a seller cannot control product durability, planned obsolescence that suppresses the value of old products (Bulow 1986; Waldman 1993, 1996b) may not be feasible. Rather than desperately removing old products from the market, the seller could launch new products later; this enhances the prices of both products and could sometimes result in higher profits. Third, although stipulating minimum levels of durability could lead to slower technological progress (Fishman and Robs 2000), it allows consumers to enjoy new products earlier, provided that the enabling technologies for the new products are available. Hence, it may benefit consumers, if for example, protracted licenses of 3G cellular networks are awarded to telecommunications companies, or long service contracts are extended to pay-TV operators and broadband Internet service providers. Finally,

[13] For example, in Fishman and Rob's (2000) model, if a seller can offer an upgrade discount or if old products are not durable, then the timing decisions of new products are always socially optimal. That is, there is no "delay" in welfare maximizing equilibria. By separating sale from product innovation, we show that delay per se exists in social optimum. A new product may *not* be sold immediately on becoming available.

facilitating upgrade or trade-in is especially important in encouraging an impatient seller to launch better products. Measures that help such a seller administer trade-in (e.g., reinforcing the credibility of buyback guarantees) or policies that support renting instead of selling a product are useful; those that prohibit the seller from discriminating against new customers or retaining controls on old products should generally be avoided.

This paper also extends the research on durable goods monopolists. Similar to that literature (e.g., Bulow 1982, 1986; Levinthal and Purohit 1989; Waldman 1993, 1996b), the seller in our study faces a time inconsistency problem. Departing from that literature, however, he cannot resolve the problem by adjusting output, R&D investment, or durability (all of these are moot in this paper). Instead, he can manipulate timing of sale. As advocated by Waldman (2003, p.140), "the problem of time inconsistency is potentially more important for other choices than for output". We have certainly shown that timing of sale per se is yet another such "other choices", and it deserves more attention because sellers have high degrees of freedom in determining when to sell new products (cf. choices of R&D, durability, or planned obsolescence that are often not subject to control by sellers because of external research, or the political and market environments).

Our study opens up several avenues of future research. First, we could allow for dynamic demands with new consumers entering the market in each period, or incorporate heterogeneity in taste for quality. Second, it would be interesting to see if competition dilutes the incentives to delay new product introductions. Third, we have assumed that the new product does not affect the quality of the old product, but this might not be the case for products that exhibit network externalities or require compatible standards (Padmanabhan et al. 1997). Finally, it may be worthwhile to study the interplay of delayed introduction and preannouncement (e.g., Bayus et al. 2001; Hendricks and Singhal 1997), the latter is commonly practiced for software, information technology and electronics products. It is instructive to investigate if preannouncement raises consumer expectations of new products, and whether delay in such a context serves the same function as in this paper.

Despite these future extensions, it is clear that the incentives of durable goods sellers to deploy advanced technologies in new products must be closely monitored, or else consumers may simply not see the light of better products.

Appendix

Proof of Proposition 1.

By comparing the profits of the seller across the four strategies {*L*, -, -}, {*L*, *H*, -}, {*L*, -, *H*}, and {-, *H*, -} in Table 1, we have the following set of inequalities:

$\pi_{\{L,-,-\}} > \pi_{\{L,H,-\}}$ if and only if $\left[\frac{1-\delta^n}{1-\delta}\right]q_L - q_L - \delta\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right]q_L\right\} > 0$, or

$$q_L > \frac{1-\delta^n}{2[1-\delta^{n-1}]}. \qquad \text{(A1)}$$

$\pi_{\{L,-,-\}} > \pi_{\{L,-,H\}}$ if and only if

$$\left[\frac{1-\delta^n}{1-\delta}\right]q_L - [1+\delta]\, q_L - \delta^2\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-2}}{1-\delta}\right]q_L\right\} > 0, \text{ or}$$

$$q_L > \frac{1-\delta^n}{2[1-\delta^{n-2}]}. \qquad \text{(A2)}$$

$\pi_{\{L,-,-\}} > \pi_{\{-,H,-\}}$ if and only if $\left[\frac{1-\delta^n}{1-\delta}\right]q_L - \delta\left[\frac{1-\delta^n}{1-\delta}\right] > 0$, or

$$q_L > \delta. \qquad \text{(A3)}$$

$\pi_{\{L,H,-\}} > \pi_{\{L,-,H\}}$ if and only if

$$q_L + \delta\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right]q_L\right\} - [1+\delta]q_L - \delta^2\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-2}}{1-\delta}\right]q_L\right\} > 0, \text{ or}$$

$$q_L < \frac{1-\delta^n}{2}. \qquad \text{(A4)}$$

$\pi_{\{L,H,-\}} > \pi_{\{-,H,-\}}$ if and only if $q_L + \delta\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right]q_L\right\} - \delta\left[\frac{1-\delta^n}{1-\delta}\right] > 0$, or

$$1 - 2\delta + \delta^n > 0. \qquad \text{(A5)}$$

$\pi_{\{L,-,H\}} > \pi_{\{-,H,-\}}$ if and only if $[1+\delta]q_L + \delta^2\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-2}}{1-\delta}\right]q_L\right\} - \delta\left[\frac{1-\delta^n}{1-\delta}\right] > 0$,

or

$$q_L > \frac{\delta[1-\delta][1-\delta^n]}{1-2\delta^2+\delta^n}. \qquad \text{(A6)}$$

(A1) to (A3) together define the necessary and sufficient conditions for q_L, δ, and *n* such that the seller would prefer the *status quo* strategy. Similarly, (A3), (A5) and (A6) define the conditions for *leapfrogging*; (A1), (A4) and (A5) define the conditions for *immediate sale*; and (A2), (A4) and (A6) define the conditions for *delayed introduction*.

To prove the corollary, observe that:

$$\frac{d}{dn}\left[\frac{1-\delta^n}{2}\right] > 0, \ \frac{d}{dn}\left\{\frac{\delta[1-\delta][1-\delta^n]}{1-2\delta^2+\delta^n}\right\} > 0, \text{ and } \frac{d}{dn}\left\{\frac{1-\delta^n}{2[1-\delta^{n-2}]}\right\} < 0.$$

Hence, the feasible region of q_L for *delayed introduction* shrinks when n increases. Finally, for all $\delta > 0$,

$$\lim_{n\to\infty}\frac{1-\delta^n}{2} = \lim_{n\to\infty}\frac{1-\delta^n}{2[1-\delta^{n-2}]} = \frac{1}{2}.$$

This implies that no values of q_L and δ could fulfill all three necessary conditions for *delayed introduction*. In other words, the seller would always choose one of the other three strategies instead of the *delayed introduction* strategy. []

Proof of Proposition 2.

Comparing the seller's profits across the two strategies, we have:

$$\begin{aligned}\pi_{\{L,H,-\}} - \pi_{\{L,-,H\}} &= q_L + \left[\frac{1-\delta^n}{1-\delta}\right]\delta - [1+\delta]q_L + \left[\frac{1-\delta^n}{1-\delta}\right]\delta \\ &= -\delta\{q_L - [1-\delta^n]\} \quad > 0\end{aligned}$$

if and only if $q_L < 1-\delta^n$. For the corollary, it suffices to show that:

$$\frac{d}{dn}[1-\delta^n] = -\delta^n \ln\delta > 0 \text{ and } \frac{d}{d\delta}[1-\delta^n] = -n\delta^{n-1} < 0.$$

Also,

$$\lim_{n\to\infty} -\delta\{q_L - [1-\delta^n]\} = -\delta\{q_L - 1\} > 0,$$

and $-\delta\{q_L - [1-\delta^n]\}$ is always positive when δ is close to but does not equal zero. Therefore, $\pi_{\{L,H,-\}} > \pi_{\{L,-,H\}}$ when $n \to \infty$ or $\delta \to 0$. []

Proof of Proposition 3.

We first consider the case with no upgrade policies. When $n_H \neq n_L$, the profits of the seller with product strategies {*L*, -, -}, {*L*, *H*, -}, {*L*, -, *H*}, and {-, *H*, -} are:

$$\pi_{\{L,-,-\}} = \left[\frac{1-\delta^{n_L}}{1-\delta}\right]q_L, \tag{A7}$$

$$\pi_{\{L,H,-\}} = q_L + \delta\left\{\left[\frac{1-\delta^{n_H}}{1-\delta}\right] - \left[\frac{1-\delta^{n_L-1}}{1-\delta}\right]q_L\right\}, \tag{A8}$$

$$\pi_{\{L,-,H\}} = [1+\delta]q_L + \delta^2\left\{\left[\frac{1-\delta^{n_H}}{1-\delta}\right] - \left[\frac{1-\delta^{n_L-2}}{1-\delta}\right]q_L\right\}, \tag{A9}$$

and

$$\pi_{\{-,H,-\}} = \delta\left[\frac{1-\delta^{n_H}}{1-\delta}\right]. \tag{A10}$$

Comparing these four profit functions, we have the following set of inequalities:

$$\pi_{\{L,-,-\}} > \pi_{\{L,H,-\}} \text{ if and only if } q_L > \frac{1-\delta^{n_H}}{2[1-\delta^{n_L-1}]}, \tag{A11}$$

$$\pi_{\{L,-,-\}} > \pi_{\{L,-,H\}} \text{ if and only if } q_L > \frac{1-\delta^{n_H}}{2[1-\delta^{n_L-2}]}, \tag{A12}$$

$$\pi_{\{L,-,-\}} > \pi_{\{-,H,-\}} \text{ if and only if } q_L > \frac{\delta[1-\delta^{n_H}]}{1-\delta^{n_L}}, \tag{A13}$$

$$\pi_{\{L,H,-\}} > \pi_{\{L,-,H\}} \text{ if and only if } q_L < \frac{1-\delta^{n_H}}{2}, \tag{A14}$$

$$\pi_{\{L,H,-\}} > \pi_{\{-,H,-\}} \text{ if and only if } 1-2\delta+\delta^{n_L} > 0, \tag{A15}$$

and

$$\pi_{\{L,-,H\}} > \pi_{\{-,H,-\}} \text{ if and only if } q_L > \frac{\delta[1-\delta][1-\delta^{n_H}]}{1-2\delta^2+\delta^{n_L}}. \tag{A16}$$

Similar to (A1) to (A6), (A11) to (A16) define a set of necessary and sufficient conditions for each product strategy to be optimal for the seller. In particular, the constraints that define the joint region (see Figure 1) for the *status quo* and *delayed introduction* strategies are:

$$q_L > \frac{\delta[1-\delta^{n_H}]}{1-\delta^{n_L}},\ q_L > \frac{1-\delta^{n_H}}{2}, \text{ and } q_L > \frac{\delta[1-\delta][1-\delta^{n_H}]}{1-2\delta^2+\delta^{n_L}}.$$

Given fixed n_L, the terms on the right-hand side of the three inequalities above increase with n_H, which means that the region for *status quo* and *delayed introduction* contracts with n_H. Further, the boundary between these two strategies is defined by (A12), which becomes more stringent as n_H increases. That is, the seller may shift from *status quo* to *delayed introduction*.

We next consider the case with an upgrade policy. When $n_H \neq n_L$, three strategies could be optimal for the seller: {*L*, -, -}, {*L*, *H*, -} and {*L*, -, *H*}. The corresponding profits are:

$$\pi_{\{L,-,-\}} = \left[\frac{1-\delta^{n_L}}{1-\delta}\right] q_L , \tag{A17}$$

$$\pi_{\{L,H,-\}} = q_L + \delta\left[\frac{1-\delta^{n_H}}{1-\delta}\right], \tag{A18}$$

and

$$\pi_{\{L,-,H\}} = [1+\delta]q_L + \delta^2\left[\frac{1-\delta^{n_H}}{1-\delta}\right]. \tag{A19}$$

As long as $n_H \geq n_L - 2$, strategy {*L*, -, -} is always dominated. The necessary and sufficient condition for *delayed introduction* becomes $\pi_{\{L,-,H\}} > \pi_{\{L,H,-\}}$, or:

$$q_L > 1 - \delta^{n_H} . \tag{A20}$$

Note that n_L does not appear in (A20). This is because with an upgrade policy, the seller could internalize obsolescence of the old product brought by the new product and capture the full utility that consumers place on the old product. The decision of whether to delay selling the new product then depends on the value that it brings to consumers, which is a function of n_H. As (A20) clearly shows, the condition for *delayed introduction* is stronger when n_H increases, which means that it is more likely for the seller to launch the new product when its durability or life span increases.

If $n_H < n_L - 2$, then $\pi_{\{L,-,-\}} > \pi_{\{L,-,H\}}$ and $\pi_{\{L,-,-\}} > \pi_{\{L,H,-\}}$ if and only if

$$q_L > \frac{1-\delta^{n_H}}{1-\delta^{n_L-2}} . \tag{A21}$$

Hence, if the durability of the new product is substantially lower than that of the old product, the *status quo* strategy could emerge as an optimal strategy for the seller (cf. Proposition 2). As in (A20), if n_H decreases, the chance for the seller to prefer delayed introduction of the new product increases. In the extreme case, when (A21) is satisfied (perhaps because the old product's quality is similar to that of the new product), he might even shelf the new product even though he is able to offer an upgrade policy. []

Proof of Proposition 4.

We first consider the case with no upgrade policies. When $\theta \neq \delta$, the profits of the seller with product strategies {*L*, -, -}, {*L*, *H*, -}, {*L*, -, *H*}, and {-, *H*, -} are:

$$\pi_{\{L,-,-\}} = \left[\frac{1-\delta^n}{1-\delta}\right] q_L, \tag{A22}$$

$$\pi_{\{L,H,-\}} = q_L + \theta\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right] q_L\right\}, \tag{A23}$$

$$\pi_{\{L,-,H\}} = [1+\delta] q_L + \theta^2\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-2}}{1-\delta}\right] q_L\right\}, \tag{A24}$$

and

$$\pi_{\{-,H,-\}} = \theta\left[\frac{1-\delta^n}{1-\delta}\right]. \tag{A25}$$

Comparing these four profit functions, we have the following set of inequalities:

$$\pi_{\{L,-,-\}} > \pi_{\{L,H,-\}} \text{ if and only if } q_L > \frac{\theta[1-\delta^n]}{[\theta+\delta][1-\delta^{n-1}]}, \tag{A26}$$

$$\pi_{\{L,-,-\}} > \pi_{\{L,-,H\}} \text{ if and only if } q_L > \frac{\theta^2[1-\delta^n]}{[\theta^2+\delta^2][1-\delta^{n-2}]}, \tag{A27}$$

$$\pi_{\{L,-,-\}} > \pi_{\{-,H,-\}} \text{ if and only if } q_L > \theta, \tag{A28}$$

$$\pi_{\{L,H,-\}} > \pi_{\{L,-,H\}} \text{ if and only if } q_L < \frac{\theta[1-\theta][1-\delta^n]}{\delta[1-\delta]+\theta[1-\delta^{n-1}]-\theta^2[1-\delta^{n-2}]}, \tag{A29}$$

$$\pi_{\{L,H,-\}} > \pi_{\{-,H,-\}} \text{ if and only if } \theta > \frac{1-\delta}{1-\delta^{n-1}}, \tag{A30}$$

and

$$\pi_{\{L,-,H\}} > \pi_{\{-,H,-\}} \text{ if and only if } q_L > \frac{\theta[1-\theta][1-\delta^n]}{[1-\delta^2]-\theta^2[1-\delta^{n-2}]}. \tag{A31}$$

Comparing against (A1) to (A3), it is obvious that when $\theta < \delta$, the necessary and sufficient conditions (A26) to (A28) for {*L*, -, -} to be optimal become weaker.

We next consider the case with an upgrade policy. When $\theta \neq \delta$, as in Proposition 2, the seller would only choose either {*L*, *H*, -} or {*L*, -, *H*} in equilibrium. The necessary and sufficient condition for *immediate sale*, {*L*, *H*, -}, is:

$$q_L < \frac{[1-\theta][1-\delta^n]}{[1-\delta^{n-1}]-\theta[1-\delta^{n-2}]}. \tag{A32}$$

Compared with $[1-\delta^n]$, it is clear that the right-hand side of (A32) is larger when $\theta < \delta$, i.e., it is more likely for the seller to choose *immediate sale* when he is impatient. []

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Table 1. Product Strategies, Prices and Profits

Product strategy	Consumer utility[+]	Price schedule with no upgrade policies	Monopolist's profit with no upgrade policies	Price schedule with an upgrade policy[++]
{*L*, -, -}	$u_{\{L,-,-\}} = \left[\frac{1-\delta^n}{1-\delta}\right] q_L$	$p_1^L = \left[\frac{1-\delta^n}{1-\delta}\right] q_L$	$\pi_{\{L,-,-\}} = \left[\frac{1-\delta^n}{1-\delta}\right] q_L$	$p_1^L = \left[\frac{1-\delta^n}{1-\delta}\right] q_L$
{-, *L*, -}	$u_{\{-,L,-\}} = \delta\left[\frac{1-\delta^n}{1-\delta}\right] q_L$	$p_2^L = \left[\frac{1-\delta^n}{1-\delta}\right] q_L$	$\pi_{\{-,L,-\}} = \delta\left[\frac{1-\delta^n}{1-\delta}\right] q_L$	$p_2^L = \left[\frac{1-\delta^n}{1-\delta}\right] q_L$
{-, -, *L*}	$u_{\{-,-,L\}} = \delta^2\left[\frac{1-\delta^n}{1-\delta}\right] q_L$	$p_3^L = \left[\frac{1-\delta^n}{1-\delta}\right] q_L$	$\pi_{\{-,-,L\}} = \delta^2\left[\frac{1-\delta^n}{1-\delta}\right] q_L$	$p_3^L = \left[\frac{1-\delta^n}{1-\delta}\right] q_L$
{*L*, *H*, -}	$u_{\{L,H,-\}} = q_L + \delta\left[\frac{1-\delta^n}{1-\delta}\right]$	$p_1^L = q_L$ $p_2^H = \left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right] q_L$	$\pi_{\{L,H,-\}} = q_L + \delta\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right] q_L\right\}$	$p_1^L = \left[\frac{1-\delta^n}{1-\delta}\right] q_L$ $p_2^{Hu} = \left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right] q_L$ $p_2^H > \left[\frac{1-\delta^n}{1-\delta}\right]$
{*L*, -, *H*}	$u_{\{L,-,H\}} = [1+\delta] q_L + \delta^2\left[\frac{1-\delta^n}{1-\delta}\right]$	$p_1^L = [1+\delta] q_L$ $p_3^H = \left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-2}}{1-\delta}\right] q_L$	$\pi_{\{L,-,H\}} = [1+\delta] q_L$ $+ \delta^2\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-2}}{1-\delta}\right] q_L\right\}$	$p_1^L = \left[\frac{1-\delta^n}{1-\delta}\right] q_L$ $p_3^{Hu} = \left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-2}}{1-\delta}\right] q_L$ $p_3^H > \left[\frac{1-\delta^n}{1-\delta}\right]$

{-, L, H}	$u_{\{-,L,H\}} = \delta q_L + \delta^2\left[\frac{1-\delta^n}{1-\delta}\right]$	$p_2^L = q_L$ $p_3^H = \left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right]q_L$	$\pi_{\{-,L,H\}} = \delta q_L + \delta^2\left\{\left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right]q_L\right\}$	$p_2^L = \left[\frac{1-\delta^n}{1-\delta}\right]q_L$ $p_3^{Hu} = \left[\frac{1-\delta^n}{1-\delta}\right] - \left[\frac{1-\delta^{n-1}}{1-\delta}\right]q_L$ $p_3^H > \left[\frac{1-\delta^n}{1-\delta}\right]$
{-, H, -}	$u_{\{-,H,-\}} = \delta\left[\frac{1-\delta^n}{1-\delta}\right]$	$p_2^H = \left[\frac{1-\delta^n}{1-\delta}\right]$	$\pi_{\{-,H,-\}} = \delta\left[\frac{1-\delta^n}{1-\delta}\right]$	$p_2^H = \left[\frac{1-\delta^n}{1-\delta}\right]$
{-, -, H}	$u_{\{-,-,H\}} = \delta^2\left[\frac{1-\delta^n}{1-\delta}\right]$	$p_3^H = \left[\frac{1-\delta^n}{1-\delta}\right]$	$\pi_{\{-,-,H\}} = \delta^2\left[\frac{1-\delta^n}{1-\delta}\right]$	$p_3^H = \left[\frac{1-\delta^n}{1-\delta}\right]$

[+] Since $q_H = 1$, it is omitted from all utility functions.
[++] The seller's profits that correspond to these price schedules are identical to the consumer utilities reported in the second column.

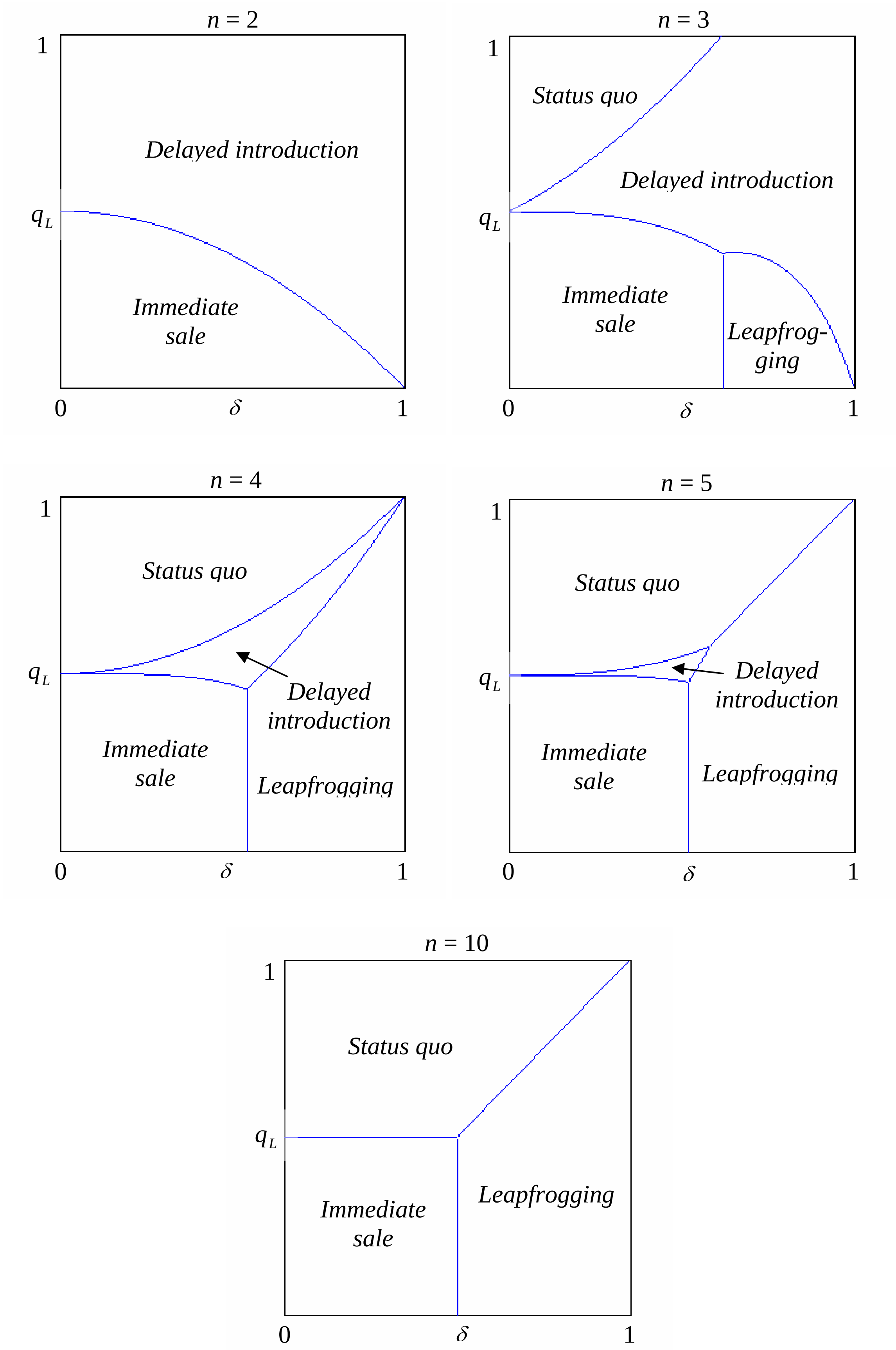


Figure 1. Optimal Product Strategies with No Upgrade Policies

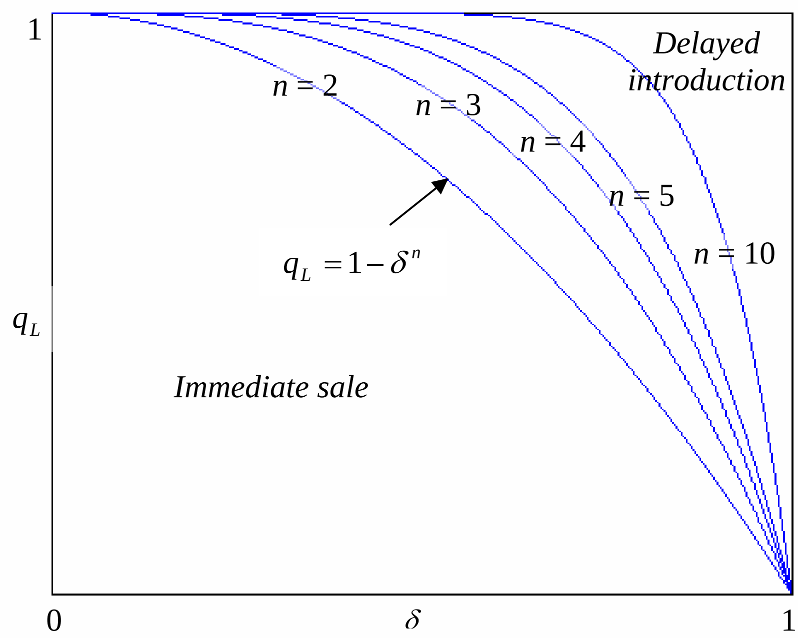
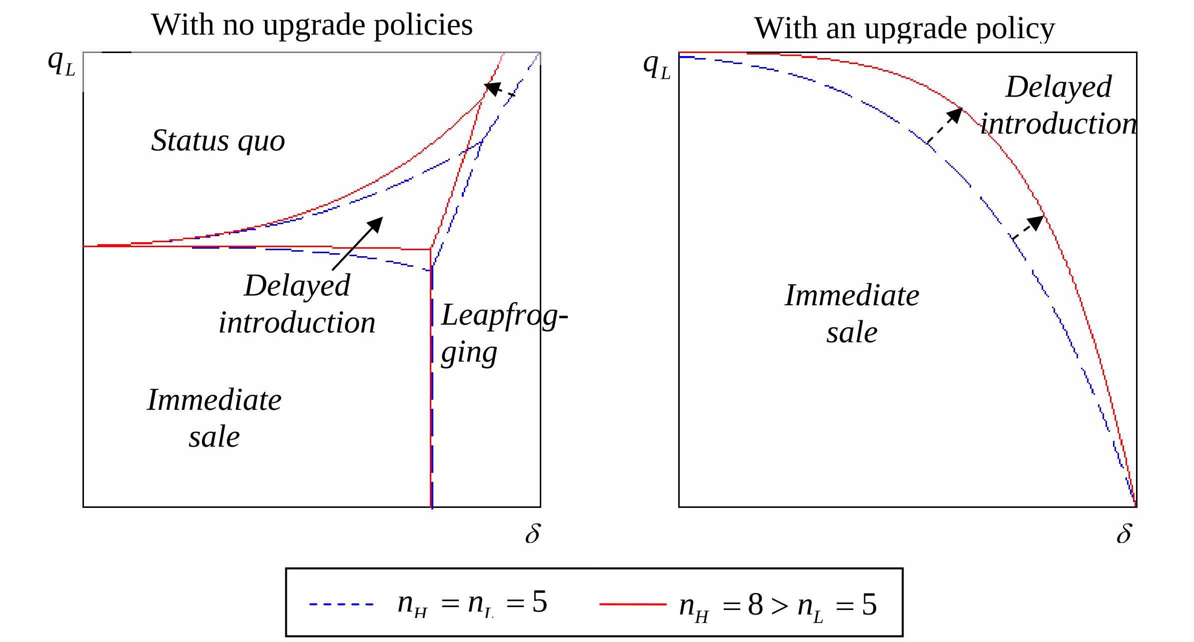


Figure 2. Optimal Product Strategies with an Upgrade Policy

(a) When n_H increases relative to n_L



(b) When n_H decreases relative to n_L

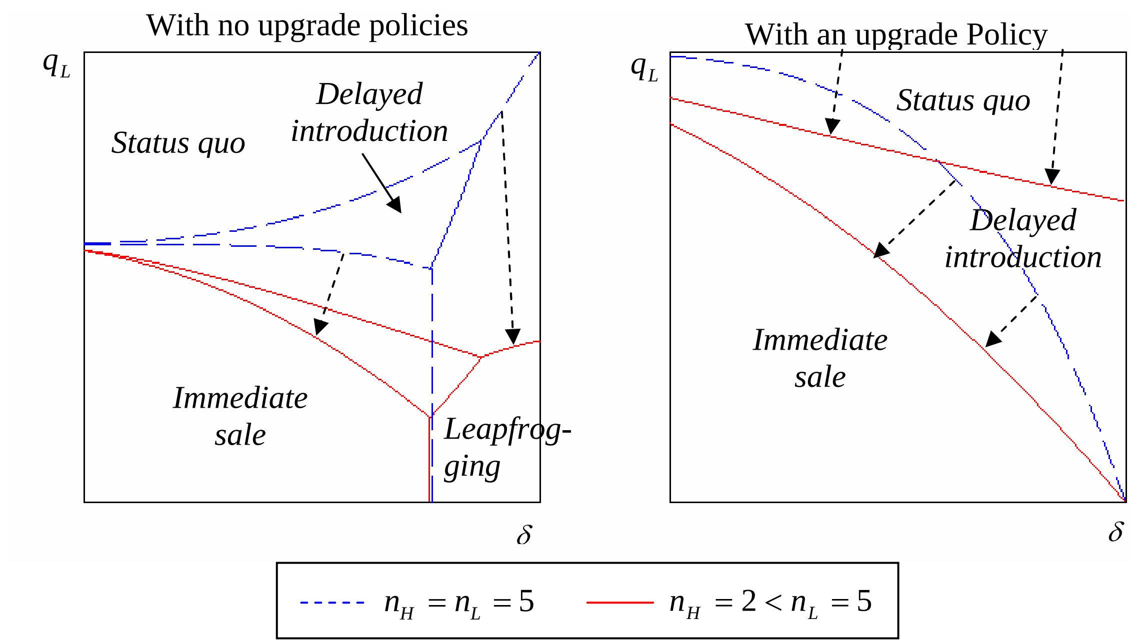


Figure 3. Optimal Product Strategies with Different Durabilities

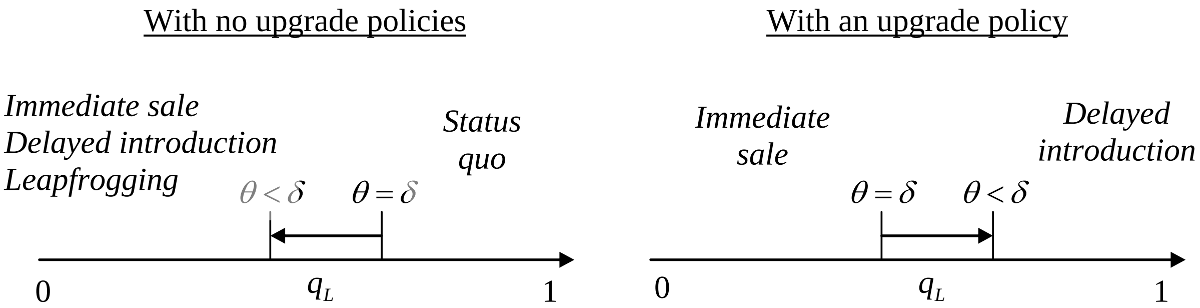


Figure 4. Optimal Product Strategies with Different Discount Factors