How Incumbent Firms Foster Expectations, Delay Launch But Still Dominate Markets for Next Generation Products

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Abstract

Consumers learn quality of many durable products through word-of-mouth information while firms launch new and improved products frequently in these markets. We examine an incumbent firm's incentive to invest in R&D, and probability of its dominance in the market for new products where consumers rely on word-of-mouth information for their purchase decision and have expectations about the new products before they are launched. When its loss due to a possible competitive entry is above a threshold, the incumbent has more incentive than the potential entrant to invest in R&D. Moreover, if the current product is more profitable, its true quality is above initial consumer priors and the quality of the new product is below a threshold, it is optimal for the incumbent to launch the new product after a time lag. The later the optimal time of launch, the greater is the incumbent's potential loss if entry occurs and greater its incentive is to invest in R&D versus that of the entrants. While potential entrants are generally thought to have more incentive to invest in a drastic innovation which results in a race to launch the new products, we show that the more drastic the innovation, the later the optimal time of launch and greater the incumbent's incentive is to invest in R&D when the value added of the new product can be conveyed to all the consumers. Only when consumers are uncertain about the value added of the new product, is the incumbent's incentive lower. We also demonstrate that by promoting consumer expectations about the new product before launch, an incumbent has more time to launch and higher probability of dominating its market.

Key Words: R&D competition, new product research, speed-to-market, consumer expectations, diffusion of innovations.

1 Introduction

New and improved versions of products are frequently introduced in many durable product markets. While many of these new and improved products are introduced by firms that which enter the market for the first time (hereafter called 'entrants'), in many cases firms that are already dominant in these markets (hereafter called 'incumbents') introduce subsequent new products and continue their dominance over a period of time. For example, Callaway Golf dominated the market golf drivers from the late eighties to the nineties launching S2H2 in 1989, Big Bertha in 1991 and Big Bertha Titanium in 1995. Each of these products provided substantial improvement over the quality of the prior product. Callaway's first major innovation, the S2H2 brought about a redistribution of weight to parts where it is more effective to hit the ball farther. The Big Bertha combined the technology of S2H2 with an oversized head to make the driver more forgiving on mis-shots. Thereafter, Big Bertha Titanium added a thinner shell of a heavier metal (Titanium) to the clubhead. This allowed the weight to move out of the center of the clubhead thereby making it hit farther as well as more forgiving to mis-shots. In this example, the incumbent frequently invests in and introduces drastic innovations in a market where consumers (golfers) rely on word-of-mouth information to make their purchase decision (Lal and Prescott 2005). Similar instances can be found in many other industries as well. Apple Computers has been dominating the market for portable music players starting with the launch of its original iPod in 2001. Apple has, over time, introduced several new and improved versions of this product such as iPod Mini, two versions of iPod Shuffle and the iPod Video. Similarly, Intel has long dominated the supplier market for personal computers with its improved versions of microprocessor in sync with what is now popularly known as Moore's Law[1].

Firms like Callaway continued to dominate the market for subsequent new products for a considerable time (1989-97) despite the presence of other firms such as Taylor Made, Ping, Titleist and Nike who had the opportunity to challenge its dominance by entering the market with improved new products. Similarly in the case of microprocessors, AMD (Advanced Micro Devices), IBM and Motorola had the opportunity to invest in R&D to develop a new product and emerge as the dominant firm in the market. While the likelihood of such

[1] In 1965, Intel co-founder Gordon Moore predicted what is now popularly known as Moore's Law. It states that the number of transistors on a chip doubles about every two years. This observation about silicon integration, made a reality by Intel, the world's largest silicon supplier, has fueled the worldwide technology revolution. (Source: http://www.intel.com/technology/mooreslaw/index.htm)

investments can be expected to result in an R&D race with an increase in the frequency of new products arriving in the market, from the incumbent's perspective early launch of an improved new product would hurt profits from an existing product. In case the current product is more profitable, due to the effect of diffusion of the products in the market, a firm which has already committed resources to it may choose to delay the arrival of the new product to maximize its profit. For example, Callaway, Intel and Apple timed the launch of their successful new products so that it gave them enough time to earn the desired profits from the current product. On the other hand, from the entrant's perspective, the sooner they launch the new product the sooner they displace the incumbents from their position of dominance and higher are their gains. For example, starting from 1997 as a result of increased competition in the golf driver industry, an increased number of new products was introduced in the market in a short time. Most firms in the market such as Ping, Taylor Made, Nike, Titleist as well as Callaway took short turns as the market leader.

The paper analyzes the effect of a firm's prior commitment in a market where consumers learn quality through word-of-mouth and have rational expectations, on its incentive to invest in R&D and the timing of launch of a new product under competitive threats . It also identifies conditions under which the firm having prior commitment to the market (the incumbent) a) is more or less likely to invest in a more drastic innovation, versus a firm that has no commitment (the entrant), and b) will launch the new product sooner or later. In particular, the paper aims to answer the following questions:

1. Who, the incumbent or the challenger has more incentive to invest in R&D and is more likely to win the market for the new product?

2. How does incumbent's timing of launch influence its incentive to invest in R&D and chance of winning the market for the new product?

3. What is the impact of a) consumer expectation of the anticipated new product, b) quality of the current and new product on the incumbent's timing of launch and chance of winning the market?

4. How does consumer uncertainty about the additional value of the new product influence the incumbent's timing of launch and chance of winning the market?

We propose a model to examine a market situation where an incumbent and an entrant decide to invest in R&D to win the race to launch a new product which diffuses in the market driven by consumer decision-making under uncertainty. The following section provides a brief review of the relevant literature.

2 Literature Review

Research on R&D (e.g., Gilbert and Newberry 1984) suggests that potential entrants have more incentives to invest in a drastic innovation than an incumbent. The studies however assume that the profits accruing to firms from innovations are instantaneous and automatic. The above examples suggest that the incumbents as well as potential entrants may have incentive to launch drastic innovations and dominate markets. We show that when the profits from new products are not realized instantaneously, the incumbents may have more incentive than potential entrants to invest in the development of drastic innovations. There may be however, advantages accruing to firms due to their being first to market in the order of entry (Robinson and Fornell 1985). Ofek and Sarvary (2003) examine a firm's advantage in terms of reputation and dynamic capabilities due to its position in the industry as an incumbent or entrant. They suggest that prior success in R&D leads to greater innovative and reputational advantages which a firm can subsequently leverage using effective advertising as opposed to further investment in R&D. We show that even when such advantages do not exist, incumbents are more likely to prevail over potential entrants in markets for new products when they have incentive to delay launch of new products.

Many scholars believe that speed to market is key to success of new products (e.g., Stalk 1988, Treacy and Wiersema 1993 and Day 1994). The examples discussed above, however, involve incumbents who launched successive innovations after a distinct time lag and yet prevailed over the potential entrants. Studies on the trade-off between the timing of launch, new product quality, and development costs (Bayus et al 1997 and Cohen et al 1996) suggest that the firms should take their time to introduce the highest possible quality. These studies however, examine the time firms need only to develop suitable quality but not the effects of consumer purchase decisions on the optimal timing of launch.

Diffusion of new products (Gatignon and Robertson 1985) can also influence a firm's investment and timing of launch decisions for a new product (Kalish and Lilien 1986). When a firm has the possibility of launching a new product while an existing product is diffusing in markets, Wilson and Norton 1989 and Mahajan and Muller 1996 show that the firm's optimal decision is to launch the new product immediately ("now") or after the market has been saturated ("never"). These studies however neither consider the decision of the firm to invest in the development of the new product nor the threat of potential entry by competitors. Moreover, these are aggregate diffusion models which do not specifically link firm decisions to consumer evaluation of quality. Individual level (micro) models of new product diffusion (e.g., Chatterjee and Eliashberg 1990, and Feder and O'Mara 1982) link consumer level choice decisions under uncertainty to aggregate diffusion captured by the Bass model (Bass 1969). Our model links consumer buying decisions to firm's marketing (demand side) and R&D investment (supply side) decisions and shows that when firm profits are realized (and deferred) over time due to the 'diffusion' of innovations as consumers learn quality from word-of-mouth information, incumbents may have a greater incentive than potential entrants to invest in R&D for drastic innovations.

Some articles in the popular business press (e.g., Butscher 1998) suggest that in markets where new products are frequently introduced, consumers skip the current product and wait for the anticipated new product. According to studies in consumer behavior (Johnson, Anderson and Fornell 1995 and Jacobson and Obermiller 1990),[2] consumer expectations of anticipated new product influence their decision to purchase existing products in the market. Despite this finding, research in new product diffusion has not adequately analyzed the impact of consumer expectations on firm decisions (Gatignon and Robertson 1991). While buyer expectations have been analyzed in the context of technology markets (Balcer and Lippman 1984, and Grenadier and Weiss 1997), it has not been analyzed for an aggregate market consisting of heterogeneous consumers. One empirical study on consumer expectations of new product quality in high technology industry by Bridges et al 1994 found that firms should moderate their new product quality in the presence of consumer expectations. They however, do not analyze the effect of new product diffusion and timing of launch.

We study why incumbents develop significantly improved new products, introduce them after a time lag and yet prevail in markets where they are constantly challenged by potential entrants. We also analyze how consumer expectations about the new product before its launch influence the decisions of the incumbent in markets where consumers learn quality of the products using word of mouth information. We show that when new products diffuse in

[2] van Raaij (1991) reviews the literature on behavioral foundations of the process of expectations formation in consumer decision making.

markets, the incumbent invests more in R&D and has a higher chance of success, the later is its optimal time of launch of the new product. The incumbent's optimal time of launch of the new product is non-zero if the ratio of the profitability of the current with respect to the new product exceeds a threshold. Note that this non-zero time of launch is driven solely by market side factors (consumer decision making) and not by development-related constraints considered earlier in the literature (e.g., Bayus et al 1997 and Cohen et al 1996). Moreover, we find that the more "drastic" as opposed to "incremental" the innovation of the new product, the later is the launch and higher the chance of the firm's winning the market when the value added of the new product is known to consumers. Thus, contrary to the "replacement effect" (Gilbert and Newberry 1984) where the entrant has a greater incentive to invest in drastic innovations since it can "replace" the incumbent as the monopolist in the market, we show that when a new product diffuses in the market, the incumbent has more incentive to invest in a drastic innovation than a potential entrant due to the "diffusion effect". Further, we show that when consumers have expectations about the anticipated new product, the incumbent launches the new product later and has a higher chance of success in winning the race against the potential entrant. The following sections present the model and key findings.

3 The Model

Our model intends to capture the typical situation of industries where an incumbent firm constantly develops improved versions of its product (new generations) but at every stage is potentially challenged by entrants. Examples of such industries would include microprocessors or the golf driver industry, among others. To describe this situation, we consider two firms, an incumbent and a potential new entrant. At time 0 the incumbent launches a product (that we subsequently call the "current" product). Potential consumers continuously learn about the value of this product from word-of-mouth information. At time 0, both firms also have the option to invest in R&D to develop a second product (hereafter called the "new" product). The additional value to the consumers offered by this new product is the same across firms, is fixed and is known to consumers.[3] The amount of R&D invested by firms

[3]Note that consumers still don't entirely know the overall value of the new product. They know only the improvement it provides over the existing one. We assume that this additional value is significant. Furthermore, this analysis also applies to the case when the additional value offered by the new product is a random variable, only the mean of which is known to consumers. In this case the results don't change as long as

only determines the marginal cost of the new product with higher R&D investment leading to lower cost. We assume Bertrand competition between the two firms, that is, the firm with lower cost (higher R&D budget) drives the other firm out of the market, while the price of the winning new product will always be the marginal cost implied by the leaving firm's R&D level.[4] Once R&D investments are made (and revealed), the winning firm considers the time to introduce the new product. If the winner is the entrant this time is obviously time $t = 0$. However, if the winner is the incumbent, then it may still consider introducing the new product later to benefit from the current product's sales. To summarize, the timing of the game is as follows: First, both firms simultaneously choose R&D levels which are immediately revealed together with the resulting costs and the price of the new product. If the winner is the entrant then it immediately introduces the new product, which then competes with the incumbent's current product. If, on the other hand the winner is the incumbent, then it also has to decide when to introduce the new product.

3.1 Consumer Decisions

We assume that the value of the current product is normally distributed with mean μ and variance σ^2 where $\mu > 0$. The variance σ^2 essentially measures the variation in the value of the product due to various idiosyncratic factors related to demand or supply (e.g. consumer fit or quality control, etc.). When a consumer buys the product s/he gets to know the true mean of its value, μ. Of course μ is not known to the remaining consumers who haven't purchased the product yet. We assume that all consumers know the true variance σ^2. Consumers are assumed to be risk neutral, but heterogeneous with respect to their prior evaluation of the current product. A consumer of type i believes that the mean value, μ of the current product at time $t = 0$, is normally distributed having a mean $m_{i,0}$ and a variance s_0^2, where $m_{i,0}$ is assumed to be completely diffuse in the population, i.e. uniformly distributed across consumers, $m_{i,0} \sim U(0,1)$. Consumers who haven't purchased yet modify their beliefs about μ based on the word of mouth information received from those who have already purchased the product, using a Bayesian Normal updating process. Specifically, at time t, an uninformed consumer of type i having a prior belief $m_{i,t-1}$ about μ and s_{t-1}^2 about its variance receives a sample of information from the adopters who have already purchased the current product

consumers don't have to learn about the improvement through word of mouth. In an extension we explore the situation when such learning is also necessary.

[4] Note that this representation is equivalent to the situation where the firm which develops the new product first receives some degree of patent protection which is common in many durable goods industry.

and are aware of the true mean, μ. The observed information consists of the average value of the product $\overline{m}_{t-1}$ received from all the adopters at $t-1$. Thus, at every instant, the adopters generate a random draw from the distribution $N\left(\mu, \sigma^2\right)$. Specifically, the updating equation, i.e. consumer i's posterior beliefs about the value of the current product at time t is given by

$$m_{i,t} = \frac{m_{i,t-1}\sigma^2 + s_{t-1}^2 \overline{m}_{t-1} x_{1,t-1}}{\sigma^2 + s_{t-1}^2 x_{1,t-1}} \quad (1)$$

$$s_t^2 = \frac{\sigma^2 s_{t-1}^2}{\sigma^2 + s_{t-1}^2 x_{1,t-1}} \quad (2)$$

where $\overline{m}_{t-1}$ is the observed average of the sample of information drawn by consumer i, and $x_{1,t-1}$ is the cumulative adoption of the current product at time $t-1$. We, normalize the total number of potential consumers to one, so x is essentially a proportion. Notice that, since consumers are continuously distributed, at any moment a certain density of consumers will purchase the product. This formulation is based on the properties of Bayesian Normal-Normal Updating Process with repeated sampling and known variance (see for example, Pratt, Raiffa and Schlaifer 1995, Chapter 9, and Feder and O'Mara 1982). Since σ^2 is known, the prior beliefs about the variance of μ, i.e. s_{t-1}^2 can essentially be thought of as a measure of confidence in the prior information, and imply an "equivalent sample size" n_{t-1} associated with the prior such that

$$\sigma^2 = s_{t-1}^2 / n_{t-1}. \quad (3)$$

The equivalent sample size captures the amount of information a consumer believes s/he has already received. Recursive summation from time 0 to $t-1$ for equations 1 and 2 results in the posterior beliefs at time t given by

$$m_{i,t} = \frac{\frac{m_{i,0}}{s_0^2} + \frac{\sum_{\tau=0}^{t-1} \overline{m}_\tau x_{1,\tau}}{\sigma^2}}{\frac{1}{s_0^2} + \frac{\sum_{\tau=0}^{t-1} x_{1,\tau}}{\sigma^2}} \quad (4)$$

$$s_t^2 = \frac{1}{\frac{1}{s_0^2} + \frac{\sum_{\tau=0}^{t-1} x_{1,\tau}}{\sigma^2}} \quad (5)$$

Combining equations 4 and 5 and substituting $n_0 = s_0^2/\sigma^2$, the equivalent sample size at time 0 associated with the sample variance s_0^2, we get the updating equation

$$m_{i,t} = \frac{m_{i,0} n_0 + \sum_{\tau=0}^{t-1} \overline{m}_\tau x_{1,\tau}}{n_0 + \sum_{\tau=0}^{t-1} x_{1,\tau}}$$

Since we consider a continuum of uninformed consumers updating their priors through Bayesian updating process which is continuous at any moment new information is available, consumer i's posterior beliefs about the value of the current product in continuous time is given by

$$m_i(t) = \frac{m_{i,0} n_0 + \int_0^t \overline{m}(\tau)\, x_1(\tau)\, d\tau}{n_0 + \int_0^t x_1(\tau)\, d\tau}$$

where $x_1(t)$ is the cumulative adoption and $\overline{m}(t)$ is the observed mean value of the sample of information obtained from all those who adopted the current product until the time t (see also Feder and O'Mara 1982). As such, we can write the above formula as:

$$m_i(t) = \frac{m_{i,0} n_0 + \mu \int_0^t x_1(\tau)\, d\tau}{n_0 + \int_0^t x_1(\tau)\, d\tau} \tag{6}$$

Because of the strong law of large numbers and because we assumed the samples to be independent $\overline{m}(t)$ converges to μ in expectations.

Denote by Δ the additional value of the new product over the current product. Δ is known to all consumers so the total value of the new product is the same as that of the current product plus this additional value.[5]

3.1.1 Decision Rules

At every moment t, each consumer decides either to buy the current product or the new product or none at all by maximizing her discounted estimate of net utility from each of these options. The consumer chooses to buy a product only if it meets two conditions (a) the estimated net surplus, i.e., the perceived valuation net of price, is positive (*individual rationality*), and (b) the estimated net surplus exceeds that of the other product (*incentive compatibility*). Consumer i's individual rationality condition for the current product is given by $m_i(t) \geqslant p_1$ where p_1 is the price. Her incentive compatibility condition before the new product is introduced is given by $m_i(t) - p_1 \geqslant \delta\left[m_i(t) + \Delta - p_{2e}\right]$ where p_{2e} is the consumer expectation about the price of the new product before it is launched[6] and δ is the discount factor. In our equilibrium analysis, we will assume rational expectations for p_{2e}. Furthermore,

[5] In the extension the consumer learns also the additional value distributed $\Delta \sim N(\nu, \psi)$, similarly, her posterior valuation is given by $\Delta_i(t) = \frac{\Delta_{i,0} k_0 + \nu \int_0^t x_2(\tau) d\tau}{k_0 + \int_0^t x_2(\tau) d\tau}$ where $x_2(t)$ is the cumulative adoption of the new product at time t and k_0 is the prior equivalent sample size.

[6] We assume rational expectations whereby $p_{2e} = p_2$, the latter being the actual price of the new product. See Appendix.

for simplicity we assume δ to be constant.[7] The same condition after the new product is introduced is $\Delta \leqslant p_2 - p_1$, which can be obtained by simply substituting $\delta = 1$ and $p_{2e} = p_2$ above. The individual rationality and the incentive compatibility conditions for the new product are given by $m_i(t) + \Delta \geqslant p_2$ and $\Delta > p_2 - p_1$ respectively. Note that if $\Delta \leqslant p_2 - p_1$, the new product has no demand. Thus, for the new product to have a market $\Delta > p_2 - p_1$ must hold. As such, for the purpose of this analysis we will hereafter assume that $\Delta > p_2 - p_1$ holds.[8] Notice, that because of our assumption on Bertrand competition, this implies that the current product loses its market completely as soon as the improved new product is introduced.

3.2 Aggregate Market Demand (Diffusion)

The market demand at every instant t for each product is obtained by adding up the consumers whose utility maximizing decision ends up in favor of the product in question.[9] The incentive compatibility condition for the current product can be restated as $m_i(t) \geqslant p_1 + \delta\frac{\Delta-(p_{2e}-p_1)}{1-\delta}$. Substituting from Equation 6 and rearranging, we get

$$m_{i,0} \geqslant p_1 + \delta\frac{\Delta - (p_{2e} - p_1)}{1-\delta} - \frac{\mu - p_1 - \delta\frac{\Delta-(p_{2e}-p_1)}{1-\delta}}{n_0}\int_0^t x_1(\tau)\,d\tau. \tag{7}$$

Consumer i adopts the current product at time t, if his/ her prior $m_{i,0}$ is greater than or equal to a critical value given by the right hand term of the above expression. We denote this term as $m_1^c(t)$. Then, the aggregate demand, denoted $x_1(t)$ is given by the probability that $m_{i,0} \geqslant m_1^c(t)$. Specifically, $x_1(t) = \Pr[m_{i,0} \geqslant m_1^c(t)] = 1 - F(m_1^c(t))$ where F is the cdf of the distribution of $m_{i,0}$ across the population of consumers that we assumed to be uniform, $U(0,1)$. Note that the demand model is regular: the cumulative demand, $x_1(t)$ is increasing in time and decreasing in price. Simplifying Equation 7 and differentiating with respect to t,

[7] The model is intractable without this simplifying assumption. The discount factor can be interpreted as the consumer's expectation or knowledge about the new product. When $\delta = 0$, the consumers have no expectations about the new product and therefore they base their judgment until the launch of the new product only on considerations about the current product. On the other hand, if $\delta = 1$ the consumers are certain that the new product will be launched.

[8] Note that if $\Delta > p_2$, a consumer who has purchased the current product also buys the new product. In that case, the demand for the new product increases by a constant term given by $x_{2Up} = x_1(T)$ at the time of launch. The qualitative results do not change in that case although the incumbent launches the new product earlier when consumers do upgrade. Proofs available with the authors.

[9] A similar pproach is used by individual level (micro) models of new product diffusion (e.g., Chatterjee and Eliashberg 1990, Feder and O'Mara 1982) who link flexible individual level choice decisions under uncertainty to aggregate demand captured by the Bass model (Bass 1969).

we get

$$\dot{x}_1(t) = \frac{\mu - p_1 - \delta\frac{\Delta-(p_{2e}-p_1)}{1-\delta}}{n_0} x_1(t), \tag{8}$$

where $\dot{x}_1(t)$ is the per period sales of the current product.[10] Solving this differential equation, we obtain the closed form solution of the cumulative aggregate demand for the current product:

$$x_1(t) = x_1(0)\, e^{\frac{\mu-p_1-\delta\frac{\Delta-(p_{2e}-p_1)}{1-\delta}}{n_0}t}.$$

The initial aggregate adoption at $t = 0$ is $x_1(0) = 1 - \left(p_1 + \delta\frac{\Delta-(p_{2e}-p_1)}{1-\delta}\right)$ which is obtained from (7) by setting $t = 0$. This represents the proportion of consumers who immediately adopt at $t = 0$. The diffusion equation simplifies therefore to

$$x_1(t) = \left[1 - \left(p_1 + \delta\frac{\Delta - (p_{2e} - p_1)}{1-\delta}\right)\right] e^{\frac{\mu-p_1-\delta\frac{\Delta-(p_{2e}-p_1)}{1-\delta}}{n_0}t}. \tag{9}$$

Note that for any diffusion to occur the following conditions have to hold:

$$\mu - \delta(\mu + \Delta - p_{2e}) > p_1 \text{ and } 1 - \delta(1 + \Delta - p_{2e}) > p_1. \tag{10}$$

In other words, the quality of the product needs to be above a certain threshold and its price needs to be below a certain level.

For the new product, assume that the diffusion of the new product starts at the time of introduction $t = T$. The new product has demand in the market only if the incentive compatibility condition, $\Delta > p_2 - p_1$ holds, i.e. the new product takes over from the old one. The individual rationality condition becomes (with the help of equation 6):

$$m_{i,0} \geqslant p_2 - \Delta - \frac{\mu + \Delta - p_2}{n_0}\left[\int_0^T x_1(\tau)\, d\tau + \int_T^t x_2(\tau)\, d\tau\right]. \tag{11}$$

where $x_2(t)$ is the cumulative adoption of the new product. Notice that until $t = T$ learning happens at the rate of x_1 (i.e. at the diffusion rate of the old product) and after T it happens at the rate of x_2 consistently with the concept of word of mouth. As before, the critical value for consumer i to adopt the next generation at time t, is that his/ her prior $m_{i,0}$ should be greater than or equal to a critical value, $m_2^c(t)$ given by

$$m_2^c(t) = p_2 - \Delta - \frac{\mu + \Delta - p_2}{n_0}\left[\int_0^T x_1(\tau)\, d\tau + \int_T^t x_2(\tau)\, d\tau\right]. \tag{12}$$

[10] Note that $\frac{\partial \dot{x}_1}{\partial \Delta} < 0$, $\frac{\partial \dot{x}_1}{\partial \mu} > 0$.

The cumulative aggregate demand (diffusion) for the next generation is therefore similarly obtained: $x_2(t) = \Pr[m_{i,0} \geqslant m_2^c(t)] = 1 - F(m_2^c(t))$. Again, differentiating with respect to t we have the instantaneous rate of demand,

$$\dot{x}_2(t) = \frac{\mu + \Delta - p_2}{n_0} x_2(t). \tag{13}$$

To find the initial conditions for the differential equation, we set $t = T$ in the expression for $x_2(t)$. Using equation (12) we get the demand for the next generation at the instant of introduction,

$$\begin{aligned} x_2(T) &= 1 + \Delta - p_2 + \frac{\mu + \Delta - p_2}{n_0} \int_0^T x_1(\tau)\, d\tau \\ &= 1 + \Delta - p_2 + \frac{\mu + \Delta - p_2}{\mu - p_1 - \delta\frac{\Delta - (p_{2e} - p_1)}{1-\delta}} [x_1(T) - x_1(0)]. \end{aligned}$$

Solving the initial value problem with $x_2(T)$ we get the cumulative demand for the next generation product:

$$\begin{aligned} x_2(t) &= x_2(T)\, e^{\frac{\mu+\Delta-p_2}{n_0}t} \\ &= \left[1 + \Delta - p_2 + \frac{\mu + \Delta - p_2}{\mu - p_1 - \delta\frac{\Delta - (p_{2e} - p_1)}{1-\delta}} \{x_1(T) - x_1(0)\}\right] e^{\frac{\mu+\Delta-p_2}{n_0}t}. \end{aligned} \tag{14}$$

The dynamic component of the demand for the next generation depends only on the true quality of the next generation net of price $(\mu + \Delta - p_2)$ and the initial perceived uncertainty represented by the initial information (sample size n_0). Note that $x_2(T)$ increases with the additional quality net of price $(\Delta - p_2)$ and with the consumer learning prior to the introduction of the next generation (captured by: $x_1(T) - x_1(0)$). It decreases with the true valuation of the current product in face of expectation about the next generation product $(\mu - p_1 - \delta\frac{\Delta-(p_{2e}-p_1)}{1-\delta})$. The more the consumers decide to wait for the next generation, the greater the demand of the new product at the instant of its introduction. This is because consumers have learnt more about quality by the time of its introduction. Note that if the current product is not introduced as in the case where the entry occurs, $x_1(T)$ and $x_1(0)$ both equal zero, and $x_2(0) = 1 + \Delta - p_2$.

3.3 R&D Technology and Firm Decisions

We assume that if a firm θ (where $\theta = I$ for the incumbent and $\theta = E$ for the entrant) bids and commits a priori to an R&D investment R_θ, its probability of success in developing a new product at a marginal cost $\underline{c}$ is $h(R_\theta)$ where h is a concave and increasing function. A Nash equilibrium set of R&D investments (R_I^*, R_E^*) are such that the optimal investment R_θ^* maximizes profits π_θ given $R_{-\theta}^*$, the optimal R&D investment of the other firm. Note that the unsuccessful firm is able to develop the new product only at a higher marginal cost given by $\overline{c} > \underline{c}$.

At the beginning of the time-line the incumbent firm is endowed with the current product and an associated marginal cost $\underline{c_1}$. We assume that the entrant can only produce the current product at a strictly higher marginal cost, $\overline{c_1}$ where $\overline{c_1} > \underline{c_1}$. So only the incumbent launches the current product at time $t = 0$. Furthermore, it will set its price at a price $p_1 = \overline{c_1} - \varepsilon$ thereby preempting the other firm from entering the market. We further assume some form of patent protection preventing the entrant from copying the innovation.

At this time both firms also have the option to invest in the development of the new product (having an additional value Δ over the current product). We assume that firms invest in R&D in a bidding game as in Gilbert and Newberry (1984). In an ensuing Bertrand equilibrium the winning firm charges a price $p_2 = \overline{c_2} - \varepsilon$ which is infinitesimally lower than the marginal cost of the losing firm. We assume that once R&D investments are made (and revealed), the winning firm considers the time to introduce the new product. If the entrant is the winner then this time is obviously time $t = 0$. However, if the incumbent is the winner, then it may still consider introducing the new product later, at time $t = T > 0$ to benefit from the current product's sales/revenues. The respective payoffs for the incumbent and the entrant are given by

$$\begin{aligned}
\pi_I(R_I, R_E) &= h(R_I)\left[\left(p_1 - \underline{c_1}\right)\int_0^T e^{-r\tau}\dot{x}_1(\tau)\,d\tau + \left(p_2 - \underline{c_2}\right)\int_T^\infty e^{-r\tau}\dot{x}_2(\tau)\,d\tau\right] \\
&\quad + \left[1 - h(R_I) - h(R_E)\right]\left(p_1 - \underline{c_1}\right)\int_0^\infty e^{-r\tau}\dot{x}_1(\tau)\,d\tau - R_I \qquad (15) \\
\pi_E(R_I, R_E) &= h(R_E)\left(p_2 - \underline{c_2}\right)\int_0^\infty e^{-r\tau}\dot{x}_2(\tau)\,d\tau - R_E \qquad (16)
\end{aligned}$$

where r is the firm's rate of interest. In the following section, we present the analysis of the game and identify the optimal action for the incumbent firm in terms of R&D investment and timing of launch of the new product. Please refer to the appendix for all proofs.

4 Incumbent Strategy When the Additional Value of the New Product is Known

We first examine the market equilibrium when consumers know the additional value of the new product. In the following propositions, we identify conditions when the incumbent has more incentive than the entrant to invest in R&D for the new product and therefore "win" the race and examine the incumbent's optimal time of launch when it "wins". Proposition 1 describes the optimal investment of the incumbent vis-à-vis the entrant as a function of the profits obtained from the current and the new products.

Proposition 1 *The incumbent invests more than the entrant if its loss in profit from introducing the new product immediately (at $t = 0$) instead of an optimal $t = T$, is above a threshold given by the ratio of its profits obtained when the new product is not introduced all with respect to that obtained when it is introduced at time zero, i.e.,* $\int_0^T e^{-r\tau}\left[\left(p_1 - \underline{c_1}\right)\dot{x}_1 - \left(p_2 - \underline{c_2}\right)\dot{x}_2\right] d\tau > \frac{\left(p_1 - \underline{c_1}\right)\int_0^\infty e^{-r\tau}\dot{x}_1 d\tau}{\left(p_2 - \underline{c_2}\right)\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau}$.

Proposition 1 demonstrates that the more the incumbent gains from an optimal delay of launch, the more incentive it has to out-bid the entrant on R&D investment. By investing more than the entrant, the incumbent not only wins the market for the new product but also gains from timing its launch to maximize profits across the two products. However its incentive to invest more than the entrant is lower if the profit from the current product is very high. Note that Gilbert and Newberry (1984) having assumed that profits are realized instantaneously at the time of launch, find that the entrant is more likely to innovate than the incumbent due to the "replacement effect" whereby the entrant "replaces" the incumbent as the monopolist in the market by launching the new product. Our results based on pure strategy equilibrium suggest that the incumbent's likley loss is due to not only a successful entry, but also its inability to launch of the new product at an optimal time (i.e., maximizing profits across the two products). Note that the greater the aggregate diffusion of the current product, the faster the diffusion of the new product since the latter has a higher known value. By launching the new product at an appropriate time (i.e., when the cumulative diffusion of the current product has reached a desired level), the incumbent maximizes its payoffs from both the products. Thus if the incumbent does not invest in the development of the new product, it loses the opportunity to increase its payoffs over and above what it earns from the current product only. The effect of diffusion of the current and new products provides incentive to the incumbent to invest in the development of the new product, which is more than the incentive of the potential entrant to "replace" the incumbent in the market with the new product only. For example, Callaway, Intel and Apple had launched their new products after a definite interval and yet prevented their potential rivals from entering the market ahead of them.

Proposition 2 *The later the incumbent's timing of launch of the new product, the greater is its incentive to invest more than the entrant and therefore lower the probability that entry occurs.*

While it is commonly believed that competitive pressures often prompt firms to launch a new product sooner, our results suggest that the incumbent (unlike the potential entrant) has an incentive to delay launch of the new product. Apart from deciding how much to invest in R&D, the incumbent also chooses the time of introduction of the new product if it "wins" the race to successfully develop the new product. The later the optimal launch of the new product for the incumbent, the more it stands to lose if an entry occurs and therefore the greater are its incentives to invest in R&D. Diffusion of innovation which results in a time-based realization of profits from an innovation has an asymmetric impact on the incentive of the incumbent and the entrant to invest in a new product. It provides more incentive to the incumbent than the entrant. For example, from 1989 until 1997 Callaway had launched three new products when there was no competing launch from other firms in the industry. From 1997 however, new products were launched more frequently and the major firms such as Callaway, Ping, Taylor Made, Titleist and Nike were able to launch the best new product in the market. Thus incumbents are more likely to win in markets the longer the interval between successive product launch.

Lemma 1 *The winning incumbent delays the launch of the new product under the following necessary conditions:*
a) the profitability ratio of the current product with respect to the new product exceeds a certain threshold, i.e., $\frac{p_1-\underline{c_1}}{p_2-\underline{c_2}} > \left(\frac{\mu+\Delta-p_2}{\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}}\right)^2$.
b) the true mean of the value of the current product exceeds the highest initial prior in the population of consumers: $\mu > 1$.
c) the additional value of the new product is within the range $\left(p_2-p_1,\overline{\Delta}\right)$.
Otherwise either firm launches the new product immediately.

When the relative profitability of the current product is above a threshold, the true mean of its value above a threshold and the additional value of the new product is below a threshold, the winning incumbent does not launch the new product immediately but only after a delay. When these conditions do not hold, the winning incumbent launches the new product as soon as possible and so does the entrant. Thus when these conditions do not hold, as noted earlier in research (Wilson and Norton 1989 and Mahajan and Muller 1996) a firm either launches the new product immediately or much later when the demand for the current product has saturated: "now or never". When the above conditions hold, however, there is a possibility of an intermediate timing of launch which explains firm behavior and market outcomes in our examples. Although Bayus et al (1997) and Cohen et al (1996) suggest an intermediate time of launch, the time of launch in their analysis is driven purely by the time required for the product development cycle which is not the case in our analysis. We show that even if there is no constraint on the firm's development cycle, there are demand side factors that lead to an intermediate time of launch.

If condition a) does not hold, that is, if the current product is less profitable, the firm introduces the new product as soon as possible to increase its overall profits. However, typically the new products cost more while at the same time they face greater competitive pressures on prices resulting in lower profitability (Paulson Gjerde, Slotnick and Sobel 2002).

Even if the current product is more profitable, the incumbent introduces the new product as soon as possible if, for example, the value of the current product is below some consumers' prior evaluations. This results in a negative word of mouth since some buyers are disappointed with their purchase and therefore some potential consumers adjust their priors downward as they receive information. This slows down the diffusion of the current product, prompting the firm to introduce the new product as soon as it can. On the other hand, if the value is higher, the positive word-of-mouth will speed up diffusion of the current, higher margin product which will also increases the demand for the new product at the time of launch. Condition b) rules out this possibility.

Condition c) ensures that consumers remain interested in buying the new product while at the same time the incumbent has incentives to sell the current product. If the additional value of the new product is less than the price difference between the two products ($\Delta < p_2 - p_1$), nobody buys the new product even if it is introduced.[11] Thus the firm gains nothing at all

[11]See discussion about incentive compatibility conditions of the consumer decisions.

by introducing the new product. Similarly if the additional value offered by the new product is so high that it overrides all other considerations, the firm introduces it as soon as possible. The subsequent analysis assumes the conditions for interior solution hold.

When the lemma does not hold, the incumbent launches the new product as soon as possible which does not need any further analysis. The incumbent delays the launch until an optimum time only when the lemma holds in which case we have the following results.

Proposition 3 *The incumbent's timing of introduction is later and the probability that the incumbent "wins" is higher under any of the following conditions:*
a) the consumers expect the new product ($\delta > 0$),
b) the value added of the new product (Δ) is higher, and
c) the true mean of the value of the current product (μ) is lower.

As noted earlier in Proposition 2, the later the incumbent's timing of introduction of the new product, the greater is its probability of success vis-à-vis the entrant's. Proposition 3 further shows the effect of consumer expectations about the new product, the additional value of the new product and the true mean value of the current product on the optimal time of introduction of the new product and the incumbent's chances of winning in the market. As shown in Lemma 1, the incumbent delays launch if the current product is more profitable than the new product since the delay attracts more consumers to buy the current product, including those who would have otherwise waited and bought the new product if introduced earlier. When consumers expect the new product ($\delta > 0$), some may choose to wait and buy the new product. This lowers the speed of diffusion of the current product. The incumbent therefore has an incentive to delay launch to induce some of these waiting consumers to buy the current product which is more profitable. On the other hand, if consumers do not expect the new product ($\delta = 0$), they decide whether or not to buy the current product irrespective of their consideration for the future. In this case, the speed of diffusion of the current product remains unaffected as there are no consumers waiting for the new product. The incumbent therefore introduces the new product relatively sooner than when consumers have expectations about the new product. Thus consumer expectations allow the incumbent more time to introduce the new product. The incumbent is better off with informed rather than myopic consumers as it has more time to launch the new product and a higher chance of success.

In this case where the additional value of the new product is known to the consumers, the higher the level of additional value of the new product, the sooner consumers buy the new product when it is launched. The speed of diffusion of the new product is therefore higher. When consumers expect the new product, they are willing to wait longer for the arrival of the new product in the market if the additional value is higher. This results in fewer consumers buying the current product which is more profitable. This results in not only a slower diffusion of the current product, but also a lower demand for the new product at the time of launch which yields lower overall profits for the firm. Note that consumer learning about the current product also boosts the demand for the new product at the time of launch. The firm therefore delays launch to allow adequate consumer learning and adoption of the current product. It is therefore optimal to delay the launch of a new product even in absence of the possible negative word-of-mouth about it (compare with monopoly results of Kalish and Lilien 1986). It is not only easier to develop and introduce incremental innovations sooner in the market than significant or drastic innovations (a supply side or R&D consideration), but also desirable from demand side considerations and R&D competition, if consumers know the additional value of the new product.

The true mean of the value of the current product has the opposite effect. As the true mean of the value increases, consumer learning speeds up diffusion of the current product. Since the diffusion of the current product reaches the desired level earlier, the incumbent introduces the new product earlier. This implies that when the consumers know the additional value of the new product, an incumbent that has achieved greater prior success in R&D in terms of developing the current product faces a stiffer challenge in terms of launching the new product earlier. On the other hand if the value of the current product is lower, the incumbent 'skims' the market with it longer without sacrificing overall profitability. This means that its timing of launch of the new product is later and its probability of success is higher.

In the following section we extend our model to allow for the case where the additional value offered by the new product is not known to the consumers. While analyzing this case we focus on the specific aspects of the incumbent's strategy which differ from those observed when the additional value is known to the consumers.

5 Incumbent Strategy When the Additional Value of the New Product is Unknown

Following the same logic of derivation as for the value of the current product (Equation 6), we obtain the Bayesian updating formula for the additional value of the new product which can be written as:

$$\Delta_i(t) = \frac{\Delta_{i,0} k_0 + \nu \int_0^t x_2(\tau)\, d\tau}{k_0 + \int_0^t x_2(\tau)\, d\tau} \tag{17a}$$

where $x_2(t)$ is the cumulative adoption of the new product at time t, ν is the true mean of the additional value of the new product and k_0 is the prior equivalent sample size.

Consumer decision rules are as follows. For consumer i the individual rationality condition for the current product remains the same as earlier: $m_i(t) \geqslant p_1$ while the incentive compatibility condition before the launch of the new product given by $m_i(t) - p_1 \geqslant m_i(t) + \Delta_{i,0} - p_{2e}$ simplifies to $\Delta_{i,0} \leqslant p_{2e} - p_1$. Consumer i therefore adopts the current product at time t if $m_i(t) \geqslant p_1$ and $\Delta_{i,0} \leqslant p_{2e} - p_1$. The consumer decisions rules are the same as in Section 2.1 with one exception. For mathematical tractability and simplicity we assume that the consumer discount factor δ equals either zero (i.e., consumers have no expectations about the new product prior to its launch) or unity (i.e., consumers have perfect expectations about the new product prior to its launch and are willing to defer their purchase). Note that in this case some consumers still buy the current product even after the new product has been introduced.

The aggregate market demand (diffusion) at every instant t for each product is obtained by adding up the consumers whose utility maximizing decision ends up in favor of the product in question. The individual rationality condition for the purchase of the current product is met if his/ her prior $m_{i,0}$ is greater than or equal to a critical value given by the right hand term of the expression

$$m_{i,0} \geqslant p_1 - \frac{\mu - p_1}{n_0} \int_0^t x_1(\tau)\, d\tau. \tag{18}$$

which we denote as $m_1^c(t)$. Note that Equation 18 is a modification of Equation 7. Both the individual rationality and incentive compatibility conditions need to be met for a consumer to purchase the current product. Specifically, the demand for the current product is given by $x_1(t) = \Pr[m_{i,0} \geqslant m_1^c(t)] \,.\, \Pr[\Delta_{i,0} \leqslant p_{2e} - p_1] = [1 - F(m_1^c(t))] \,.\, G(p_{2e} - p_1)$ where F and G are the respective cdfs of the distribution of $m_{i,0}$ and $\Delta_{i,0}$ that we assumed to be uniform,

$U(0,1)$. From Equation 18, we have

$$x_1(t) = \left[1 - F\left(p_1 - \frac{\mu - p_1}{n_0}\int_0^t x_1(\tau)\,d\tau\right)\right] \cdot G(p_{2e} - p_1). \tag{19}$$

Simplifying and differentiating with respect to t, we get

$$\dot{x}_1(t) = (p_{2e} - p_1)\frac{\mu - p_1}{n_0}x_1, \tag{20}$$

where $\dot{x}_1(t)$ is the per period sales of the current product.[12] Solving this differential equation, we obtain the closed form solution of the cumulative aggregate demand for the current product:

$$x_1(t) = x_1(0)(p_{2e} - p_1)\, e^{\frac{\mu - p_1}{n_0}t}.$$

The initial aggregate adoption at $t = 0$ is $x_1(0) = 1 - p_1$, which is obtained from (19) by setting $t = 0$. This represents the proportion of consumers who immediately adopt at $t = 0$. The diffusion equation simplifies therefore to

$$x_1(t) = (1 - p_1)(p_{2e} - p_1)\, e^{\frac{\mu - p_1}{n_0}t}. \tag{21}$$

Note that for any diffusion to occur the following conditions have to hold:

$$\mu > p_1 \text{ and } 1 > p_1. \tag{22}$$

In other words, the quality of the product needs to be above a certain threshold and its price needs to be below a certain level. Note that these conditions are automatically satisfied if those in (10) are satisfied.

Assume that the new product is launched at $t = T$. The individual rationality of the current product remains the same whereas the incentive compatibility condition reduces to

$$\Delta_{i,0} \leqslant p_2 - p_1 - \frac{\nu - p_2 + p_1}{k_0}\int_0^t x_2(\tau)\,d\tau. \tag{23}$$

(derived from the Equation 17a). The incentive compatibility condition is met if consumer i's prior $\Delta_{i,0}$ is lower than or equal to a critical value given by the right hand term of the above expression, $\Delta_0^c(t)$. This change is due to the fact that consumers start receiving word-of-mouth information also on the value added from the new product. Specifically, after the introduction of the new product the demand for the current product is given by

$$x_{1A}(t) = \Pr\left[m_{i,0} \geqslant m_1^c(t)\right].\Pr\left[\Delta_{i,0} \leqslant \Delta_0^c(t)\right] = \left[1 - F\left(m_1^c(t)\right)\right].G\left(\Delta_0^c(t)\right). \tag{24}$$

[12] Note that $\frac{\partial \dot{x}_1}{\partial p_{2e}} < 0$, $\frac{\partial \dot{x}_1}{\partial \mu} > 0$.

Similarly, the demand for the new product is given by

$$x_2(t) = \Pr\left[m_{i,0} \geqslant m_1^c(t)\right].\Pr\left[\Delta_{i,0} > \Delta_0^c(t)\right] = \left[1 - F\left(m_1^c(t)\right)\right].\left[1 - G\left(\Delta_0^c(t)\right)\right]. \tag{25}$$

Simplifying the above, differentiating with respect to t and rearranging, we get the instantaneous demands of the current and the new product respectively after the launch of the new product:

$$\begin{aligned} \dot{x}_{1A}(t) &= \frac{\mu - p_1}{n_0}\frac{x_{1A}^2(t)}{x_{1A}(t)+x_2(t)} - \frac{\nu - p_2 + p_1}{k_0}\left[x_{1A}(t)+x_2(t)\right]x_2(t) \\ \dot{x}_2(t) &= \frac{\mu - p_1}{n_0}\frac{x_{1A}(t).x_2(t)}{x_{1A}(t)+x_2(t)} + \frac{\nu - p_2 + p_1}{k_0}\left[x_{1A}(t)+x_2(t)\right]x_2(t) \end{aligned} \tag{26}$$

To find the initial conditions for the differential equation, we set $t = T$ in equation 21 and using the critical value $\Delta_0^c(t = T)$ in Equation 25, we get

$$x_{1A}(T) = (1 - p_1)(p_2 - p_1)\exp\left[\frac{\mu - p_1}{n_0}T\right] \tag{27}$$

and

$$x_2(T) = x_{1A}(T)(1 - p_2 + p_1). \tag{28}$$

The firm decisions are exactly the same as in the earlier case. The only change is in the demand equations in the firms' pay-off functions where the incumbent continues to obtain revenues from the current product even after the new product is launched. The respective payoffs for the incumbent and the entrant are given by

$$\begin{aligned} \pi_I(R_I, R_E) &= h(R_I)\left(p_1 - \underline{c_1}\right)\Big[\left\{\int_0^T e^{-r\tau}\dot{x}_1(\tau)\,d\tau + \int_T^\infty e^{-r\tau}\dot{x}_{1A}(\tau)\,d\tau\right\} \\ &\quad + \left(p_2 - \underline{c_2}\right)\int_T^\infty e^{-r\tau}\dot{x}_2(\tau)\,d\tau\Big] \\ &\quad + \left[1 - h(R_I) - h(R_E)\right]\left(p_1 - \underline{c_1}\right)\int_0^\infty e^{-r\tau}\dot{x}_1(\tau)\,d\tau - R_I \end{aligned} \tag{29}$$

$$\pi_E(R_I, R_E) = h(R_E)\left(p_2 - \underline{c_2}\right)\int_0^\infty e^{-r\tau}\dot{x}_2(\tau)\,d\tau - R_E. \tag{30}$$

The following propositions describe the incumbent's optimal strategies and its probability of winning in the market when the value added of the new product is unknown.

Proposition 4 *The incumbent invests more than the entrant if its loss in profit from introducing the new product immediately (at $t = 0$) instead of an optimal $t = T$, is above a threshold given by the ratio of its profits when the new product is not introduced at all with respect to that obtained when it is introduced at time zero.*

This is exactly the same as Proposition 1 and the explanation follows the same logic. There is a change however in the conditions when the incumbent has more incentive than the entrant to invest in R&D for the development of the new product as stated below.

Proposition 5 *When the consumers are uncertain about value added of the new product, the later the incumbent's optimum time of launch, the greater is its incentive to invest more in R&D than the entrant, if and only if at the time of launch, the drop in the instantaneous profit from the current product is higher than the instantaneous profit from the new product, i.e.,* $\left(p_1 - \underline{c_1}\right)\left[\dot{x}_1(T) -, \dot{x}_{1A}(T)\right] \geqslant \left(p_2 - \underline{c_2}\right)\, \dot{x}_2(T)$.

When the consumers are uncertain about the additional value of the new product and the condition $\left(p_1 - \underline{c_1}\right)\left[\dot{x}_1(T) - \dot{x}_{1A}(T)\right] \geqslant \left(p_2 - \underline{c_2}\right)\, \dot{x}_2(T)$ holds, the later the incumbent's optimal time of launch, the greater is its incentive to invest in the development of the new product. In other words, if at the time of launch, the drop in its profit from the current product is greater than the instantaneous profit from the new product, the later the incumbent's optimum time of launch, the more incentive it has to invest in R&D. Thus if the incumbent were to suffer a sharper drop in profit at the time of launch of the new product, the more incentive it has to compensate this drop by obtaining profit from the new product. Note that in this case the incumbent continues to get revenues from the current product even after the launch of the new product. Since the rate of diffusion of the current product drops at the time of the new product launch, the starting conditions determine the extent of the overall drop in profit from the current product. The incumbent has more incentive to invest in R&D if that drop is higher. On the other hand, if the drop in profit is lower than the instantaneous profit from the new product, the sooner the time of launch, the more incentive the incumbent has to increase its profit by launching the new product which more than compensates its drop in profit from the current product. This result is therefore driven by the fact that when the additional value of the new product is unknown, the race to the market for the new product is less intense as the market also allows the current product to diffuse, albeit at a slower rate.

Lemma 2 *When the value added of the new product is uncertain, the incumbent delays the introduction of the new product under the following necessary conditions:*
a) the profitability of the current product exceeds that of the new product, i.e., $p_1 - \underline{c_1} > p_2 - \underline{c_2}$
b) the difference between the prices of the new and the current product is below a threshold: $p_2 - p_1 < 1/2$.

Otherwise either firm launches the new product immediately.

When the value added of the new product is unknown, the incumbent has an incentive to delay if the new product is less profitable and the difference in prices of the new and the current products is below 1/2. This is similar to, but less restrictive than Lemma 1. The difference here is about the condition on price difference. Even if the new product is less profitable the incumbent launches the new product as soon as possible if its price is above a threshold. Because the two products diffuse simultaneously after launch, if the price difference between the new and the current products is high, the rate of diffusion of the new product is slower, resulting in even lower present value profitability in addition to the fact that the new product is already less profitable. By launching sooner, the incumbent induces consumers to learn faster about the value added of the new product as well as learning about the value of the current product, which leads to a faster diffusion and therefore higher present value profit stream from the new product. Note that the simultaneous diffusion of the two products implies that the incumbent does not forego the profits from the current product entirely by launching the new product earlier.

As in the earlier case, the incumbent delays the launch until an optimum time only when this lemma holds in which case we have the following results.

Proposition 6 *When the value added of the new product is uncertain, the incumbent's timing of introduction is later and, consequently, the probability that the incumbent succeeds in launching the next generation is higher under any of the following conditions:*
a) the consumers expect the new product,
b) the value added of the new product is lower, and
c) the true mean of the value of the current product is higher (lower) if it is below (above) a threshold.

As in the earlier case, when the consumers have rational expectations about the new product before launch, the later the incumbent launches the new product. However, the higher the true mean of the additional value of the new product the sooner is the launch. This result is just the reverse of that in the earlier case where the additional value of the new product is known. We show that when the value added of the new product is unknown, the results of Gilbert and Newberry (1982) that the more drastic the nature of the innovation, the lower the incentive the incumbent has to invest in R&D, holds. If consumers are uncertain about the additional value of the new product, they continue to learn both the value of the current product as well as the value added of the new product after the launch, albeit the former less effectively than before launch. By delaying launch, the incumbent benefits from the unaffected and faster consumer learning about the value of the current product before launch when the true mean of the value added of the new product is lower and vice versa.

When the true mean value of the current product is below a threshold, the incumbent delays the launch of new product further, the higher the true mean of the value of the current product. This result is also different from the earlier case. When the true mean of the value of the current product is below a threshold, delaying launch allows the slower consumer learning to pick up to a desired level before the new product is launched. This result is the same as when the additional value of the new product is known.

However, when the true mean is above a threshold, we have a different result. When the true mean of the value of the current product is above a threshold, the consumer learning is faster and therefore reaches a desired level sooner prompting the incumbent to launch the new product earlier. In this case therefore, the more the incumbent's R&D has achieved before, the more time it has to launch the new product and more it invests.

6 Conclusion

We show that in durable goods markets where consumers cannot evaluate the quality of a product before purchase and rely on word-of-mouth information for their purchase decision, incumbent firms may have more incentive than potential entrants to invest in the development of a new and improved product. While a potential entrant invests in the development of a new product to "replace" the incumbent in the market by launching the new product, the incumbent invests in the development of the new product to increase its profit beyond what it gets from the current product. When a new product is an improved version of an existing product, higher aggregate diffusion of the current product leads to a faster diffusion of the new product. In such cases, an incumbent firm balances the faster rate of diffusion of the new product with the potentially lower profit margin it offers. Clearly, if the new product profit margin is greater than that of the current product, the incumbent (as well as the entrant) has an incentive to develop and launch the new product. On the other hand, if the new product profit margin is lower, the incumbent has an incentive to launch the new product after having obtained the higher profits from the current product. The incumbent therefore earns a higher present-value profit by launching the new product. It chooses the timing of launch to maximize present-value profits across the diffusion of the two products. It launches the new product when the aggregate diffusion of the existing product has reached a desired level. If entry occurs, the incumbent stands to lose the higher profits from the current product as well as that from the new product which would have diffused at a faster rate if launched at an appropriate time. Thus the incumbent has more incentive to invest in the development of a new product than a potential entrant (the latter being driven only by the opportunity to "replace" the incumbent in the market by launching the new product). This explains why in many markets, firms like Callaway, Apple (in case of iPods), Intel and Microsoft (Windows) retained their dominance by launching successive generations of new products.

When faced with the threat of competitive entry, it is commonly believed that a firm launches a new product sooner. Our results show that when incumbent firms are more likely to dominate markets for new products, the later is the optimum time of launch. The later the incumbent's optimal time of launch of the new product, the more it stands to lose if an entry occurs and therefore more it invests in the development of the new product relative to the potential entrant. This explains why firms like Callaway, Apple, Intel and Microsoft dominated their respective industries while they launched successive new products after a considerable lag. Callaway, for example, dominated the market for golf drivers during the early 90s when they launched a new product every three or four years. Thereafter others such as Ping, Titleist, Taylor Made and Nike caught up as Callaway launched new products more frequently. Thus in markets for sequential generations of new products, incumbent firms have higher chances of dominating the market the later they launch the new product.

Another commonly held determinant of the optimal timing of launch of a new product is the development cycle. Firms sometimes invest heavily midway through the development cycle or "crash" their R&D projects to reduce the time to market for the new product. Our analysis suggest that crashing R&D projects may not always be optimal in case of markets characterized by diffusion of new products where the existing product is more profitable. Thus, even if the new product were fully developed, it may not always be optimal to launch it immediately. Conversely, depending on demand side factors, an incumbent firm may have more time to develop a new product. Irrespective of the time required for development, when consumers have prior expectations about the new product, the incumbents have more time for its development. When new products offer tangible value added over the current products, firms can convey the value added to the consumers. When the value added of the new product over the existing product is known, the greater the value added of the new product or the lower the true mean value of the existing product, the later is the time of launch and consequently higher is the probability of the incumbents success in the market for the new product.

On the other hand, when the value added of the new product over the existing product is not considerably tangible, different consumers have different beliefs about the value-added. In these conditions, the current product continues to diffuse in the market even after the new product has been introduced. Thus the greater the true mean value added of the new product, the sooner is the incumbent's optimum timing of launch. Thus the greater the magnitude of innovation, the sooner the incumbent must launch the new product.

Diffusion of products gives more incentive to the incumbent than the entrant to invest in R&D and opportunity to launch the new product after a time lag irrespective of the supply side (development cycle-related) constraints on the time of launch. Our analysis shows that there may be demand side slack for managing R&D projects where consumers use word-of-mouth information for decision-making and may have rational expectations about the new products before launch.

References

[1] Balcer, Yves and Steve A. Lippman (1984) " Technological Expectations and Adoption of Improved Technology" *Journal of Economic Theory*, 34, 292–318.

[2] Bass, Frank M. (1969) *A New Product Growth for Model Consumer Durables* Management Science, January 15, 5, 215–227.

[3] Bayus, Barry L., Sanjay Jain, and Ambar G. Rao (1997) "Too little, too early: Introduction timing and new product performance in the personal digital assistant industry" *Journal of Marketing Research*, 34, 1, 50–63.

[4] Bridges, Eileen, Chi Kin (Bennet) Yim and Richard A. Briesch (1995) "A High-Tech Product Market Share Model with Customer Expectations" *Marketing Science*, 14, 1, 61–81..

[5] Butscher, S.A. (1998) "Leapfrogging: When buyers wait"*. Brandweek*, New York, March 2.

[6] Chatterjee, Rabikar and Jehoshua Eliashberg (1990) "The Innovation Diffusion Process in a Heterogeneous Population: A Micromodeling Approach" *Management Science*, 36, 9, 1057–1079.

[7] Chiang, A.C (1992). Elements of Dynamic Optimization. McGraw-Hill, Singapore.

[8] Cohen, Morris A., Jehoshua Eliashberg and Teck-Hua Ho (1996) "New Product Development: The Performance and Time-to-Market Trade-off ". *Management Science*, 42, 2, 173–186.

[9] Day, George S. (1994) "The Capabilities of Market-Driven Organizations" *Journal of Marketing*, 58, 4, 37–52.

[10] Feder, Gershon and Gerald T. O'Mara (1982) "On Information and Innovation Diffusion: A Bayesian Approach" *American Journal of Agricultural Economics*, February, 145–147.

[11] Gatignon, Hubert and Thomas S. Robertson (1991) "Innovative Decision Processes" in Thomas S. Robertson and Harold H. Kassarjian eds. *Handbook of Consumer Behavior*, Prentice Hall Inc. New Jersey, 316–348.

[12] Gatignon, Hubert and Thomas S. Robertson (1985) "A propositional Inventory for New Diffusion Research" *Journal of Consumer Research*, 11, 4, 859–867.

[13] Gilbert, Richard J. and David M.G. Newberry (1984) "Uncertain Innovation and the Persistence of Monopoly: Comment" *The American Economic Review*, 74, 1, 238–242.

[14] Gilbert, Richard J. and David M.G. Newberry (1982) "Preemptive Patenting and the Persistence of Monopoly" *The American Economic Review*, 72, 3, 514–526.

[15] Grenadier, Steven R. and Allen M. Weiss (1997) "Investment in Technological Innovations: An Options Pricing Approach" *Journal of Financial Economics*, 44, 397–416.

[16] Jacobson, Robert and Carl Obermiller (1990) "The Formation of Expected Future Price: A Reference Price for Forward-Looking Consumers" *Journal of Consumer Research*, 16, 4, 420–432.

[17] Johnson, Michael D., Eugene W. Anderson and Claes Fornell (1995) "Rational and adaptive performance expectations in a customer satisfaction framework" *Journal of Consumer Research*, 21, 4, 695–707.

[18] Kalish, Shlomo and Gary L. Lilien (1986) "A Market Entry Timing Model for New Technologies" *Management Science*, 32, 2, 194–205.

[19] Lal, Rajiv and Edith D. Prescott (2005) "Callaway Golf Company" *Harvard Business Case* (9-501-019).

[20] Mahajan, Vijay and Eitan Muller (1996) "Timing, Diffusion, and Substitution of Successive Generations of Technological Innovations: The IBM Mainframe Case" *Technological Forecasting and Social Change*, 51, 109–132.

[21] Ofek, Elie and Miklos Sarvary (2003) "R&D, Marketing, and the Success of Next-Generation Products" *Marketing Science,* 22, 3, 355–370.

[22] Paulson Gjerde, Kathy A., Susan A. Slotnick and Matthew J. Sobel (2002). "New Product Innovation with Multiple Features and Technology Constraint".Management Science, 48, 10, 1268-1284.

[23] Pratt, J. W., Raiffa, H. & Schlaifer, R. (1995). Introduction to Statistical Decision Theory. MIT Press, Cambridge, MA.

[24] Robinson, William T. and Claes Fornell (1985). "Sources of Market Pioneer Advantages in Consumer Goods Industries", *Journal of Marketing Research.* 22 (August), 305-17.

[25] Stalk Jr., George (1988) "Time- The Next Source of Competitive Advantage", *Harvard Business Review*, July–August, 41–51.

[26] Treacy, Michael and Fred Wiersema (1993) "Customer Intimacy and Other Value Disciplines", *Harvard Business Review*, Jan–Feb, 84–93.

[27] van Raaij, W. Fred (1991) "The Formation and use of Expectations in the Consumer Decision Making" in Thomas S. Robertson and Harold H. Kassarjian eds. *Handbook of Consumer Behavior*, Prentice Hall Inc., New Jersey, 401–418..

[28] Wilson, Lynn O. and John A. Norton (1989) "Optimal Entry Timing for a Product Line Extension" *Marketing Science*, 8, 1, 1–17.

Appendix

Proof of Proposition 1

From the first order conditions $\frac{\partial \pi_I(R_I,R_E^*)}{\partial R_I}=0$ and $\frac{\partial \pi_I(R_I^*,R_E)}{\partial R_E}=0$ (refer Equations 15 and 16), we have

$$\begin{aligned}&\frac{\partial h(R_I)}{\partial R_I}\left[(p_1-\underline{c_1})\int_0^T e^{-r\tau}\dot{x}_1 d\tau+(p_2-\underline{c_2})\int_T^\infty e^{-r\tau}\dot{x}_2 d\tau\right]\\&\qquad-\frac{\partial h(R_I)}{\partial R_I}(p_1-\underline{c_1})\int_0^\infty e^{-r\tau}\dot{x}_1 d\tau=1,\text{ and}\\&\qquad\frac{\partial h(R_E)}{\partial R_E}(p_2-\underline{c_2})\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau=1.\end{aligned}$$

which solve respectively for R_I^* and R_E^*.
Considering the specific functional form $h(R_\theta)=1-e^{-R_\theta}$, we have $h'(R_\theta)=e^{-R_\theta}$. The first order conditions simplify as

$$\begin{aligned}e^{R_I}&=(p_1-\underline{c_1})\int_0^T e^{-r\tau}\dot{x}_1 d\tau+(p_2-\underline{c_2})\int_T^\infty e^{-r\tau}\dot{x}_2 d\tau-e^{-R_E}(p_1-\underline{c_1})\int_0^\infty e^{-r\tau}\dot{x}_1 d\tau\\e^{R_E}&=(p_2-\underline{c_2})\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau\end{aligned}$$

from which we get the incumbent's reaction function

$$R_I^*(R_E)=\ln\left[(p_1-\underline{c_1})\int_0^T e^{-r\tau}\dot{x}_1 d\tau+(p_2-\underline{c_2})\int_T^\infty e^{-r\tau}\dot{x}_2 d\tau-e^{-R_E}(p_1-\underline{c_1})\int_0^\infty e^{-r\tau}\dot{x}_1 d\tau\right].$$

Note that and the Nash equilibrium investments in R&D are given by

$$R_I^*=\ln\left[(p_1-\underline{c_1})\int_0^T e^{-r\tau}\dot{x}_1 d\tau+(p_2-\underline{c_2})\int_T^\infty e^{-r\tau}\dot{x}_2 d\tau-\frac{(p_1-\underline{c_1})\int_0^\infty e^{-r\tau}\dot{x}_1 d\tau}{(p_2-\underline{c_2})\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau}\right] \quad (31)$$

$$R_E^*=\ln\left[(p_2-\underline{c_2})\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau\right]. \quad (32)$$

The condition for $R_I^*>R_E^*$ using the Equations 31 and 32 is given by

$$\int_0^T e^{-r\tau}\left[(p_1-\underline{c_1})\dot{x}_1-(p_2-\underline{c_2})\dot{x}_2\right]d\tau>\frac{(p_1-\underline{c_1})\int_0^\infty e^{-r\tau}\dot{x}_1 d\tau}{(p_2-\underline{c_2})\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau}, \quad (33)$$

Note that $\int_0^T e^{-r\tau}\left[(p_1-\underline{c_1})\dot{x}_1-(p_2-\underline{c_2})\dot{x}_2\right]d\tau$ is the winning incumbent's loss of profit if it introduces the new product immediately at time $t=0$ instead of $t=T$, $(p_1-\underline{c_1})\int_0^\infty e^{-r\tau}\dot{x}_1 d\tau$ is the incumbent's profit if the new product is never introduced and $(p_2-\underline{c_2})\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau$ is the profit from launching the new product immediately (at $t=0$).
Q.E.D.

Proof of Proposition 2

Follows from the partial derivative of the difference of R_I^* and R_E^* from Equations 31 and 32, i.e., $\frac{\partial\left(R_I^*-R_E^*\right)}{\partial T}>0$.
Q.E.D.

Proof of Lemma 1

Note that if it wins the market for the new product, the incumbent also decides the timing of introduction of the new product which is given by

$$T^* = \arg\max\left\{\left(p_1-\underline{c_1}\right)\int_0^T e^{-r\tau}\dot{x}_1 d\tau + \left(p_2-\underline{c_2}\right)\int_T^\infty e^{-r\tau}\dot{x}_2 d\tau\right\}. \tag{34}$$

We can therefore obtain the first order condition (FOC),[1]

$$\left(p_1-\underline{c_1}\right)\dot{x}_1(T)-\left(p_2-\underline{c_2}\right)\dot{x}_2(T)=0. \tag{35}$$

Simplifying further, substituting $p_{2e}=p_2$ under rational expectations, substituting and rearranging, we have

$$x_1(T)=\frac{\left(p_2-\underline{c_2}\right)(\mu+\Delta-p_2)(\mu-1)\frac{\Delta-(p_2-p_1)}{1-\delta}}{\left(p_1-\underline{c_1}\right)\left(\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}\right)^2-\left(p_2-\underline{c_2}\right)(\mu+\Delta-p_2)^2}.$$

Solving for T we get the optimal time

$$T^*=\frac{n_0}{\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}}\ln\frac{\left(p_2-\underline{c_2}\right)(\mu+\Delta-p_2)(\mu-1)\frac{\Delta-p_2+p_1}{1-p_1-\delta(1+\Delta-p_2)}}{\left(p_1-\underline{c_1}\right)\left(\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}\right)^2-\left(p_2-\underline{c_2}\right)(\mu+\Delta-p_2)^2} \tag{36}$$

To check the second order sufficient condition (SOC) for a unique maximum, we consider the second derivative of the objective functional:

$$\left(p_1-\underline{c_1}\right)\left[(-r)e^{-rT}\dot{x}_1(T)+e^{-rT}\ddot{x}_1(T)\right]-\left(p_2-\underline{c_2}\right)\left[(-r)e^{-rT}\dot{x}_2(T)+e^{-rT}\ddot{x}_2(T)\right]$$

which using the FOC simplifies to $e^{-rT^*}\left[\left(p_1-\underline{c_1}\right)\ddot{x}_1(T^*)-\left(p_2-\underline{c_2}\right)\ddot{x}_2(T^*)\right]$. Differentiating Equations 8 and 13 with respect to t we get

$$\begin{aligned}\ddot{x}_1(t) &= \frac{\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}}{n_0}\dot{x}_1(t), \text{ and}\\ \ddot{x}_2(t) &= \frac{\mu+\Delta-p_2}{n_0}\dot{x}_2(t)\end{aligned}$$

[1] Note that the integrand functions F in the objective functional $\int_0^T F(\tau,x,\dot{x})\,d\tau$ in the argument in Equation (34) is of the form $F(\tau,\dot{x})$, implying that $F_x=0$. The first order necessary condition for calculus of variations, the Euler's equation for such an objective functional reduces to $dF_{\dot{x}}/d\tau=0$, with the solution $F_{\dot{x}}=\mathit{constant}$ determined only by the limits of the definite integral. In other words, in this case, the extremal values of the integrands depend only on the limits of the integrals (see for example Chiang 1992).

Using these and the FOC to further simplify the SOC, we get

$$e^{-rT^*}\left(p_2-\underline{c_2}\right)\dot{x}_2\left(T^*\right)\left[-\frac{\Delta-(p_2-p_1)}{(1-\delta)\,n_0}\right]<0$$

Since the SOC holds, T^* yields a maximum.

Note that we can obtain the incumbent's optimal time of introduction for 'myopic' consumers, i.e., when they do not have any expectations about the new product by simply putting $\delta=0$ above in Equation 36. The resulting expression is given by

$$T_N^*=\frac{n_0}{\mu-p_1}\ln\frac{\left(p_2-\underline{c_2}\right)(\mu+\Delta-p_2)(\mu-1)\frac{\Delta-p_2+p_1}{1-p_1}}{\left(p_1-\underline{c_1}\right)(\mu-p_1)^2-\left(p_2-\underline{c_2}\right)(\mu+\Delta-p_2)^2} \tag{37}$$

From Equation 36 we have a) $\frac{p_1-\underline{c_1}}{p_2-\underline{c_2}}>\left(\frac{\mu+\Delta-p_2}{\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}}\right)^2$;
b) $\mu>1$;
c) The optimal time is zero if the term inside the logarithm equals unity, i.e., $\left(p_2-\underline{c_2}\right)(\mu+\Delta-p_2)(\mu-1)\frac{\Delta-p_2+p_1}{1-p_1-\delta(1+\Delta-p_2)}=\left(p_1-\underline{c_1}\right)\left(\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}\right)^2-\left(p_2-\underline{c_2}\right)(\mu+\Delta-p_2)^2$ which is cubic in Δ which has at least one root $\overline{\Delta}$, the value added beyond which the optimal time of introduction is zero. The term inside the logarithm becomes infinity if $\left(p_1-\underline{c_1}\right)\left(\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}\right)^2=\left(p_2-\underline{c_2}\right)(\mu+\Delta-p_2)^2$ which solves as $\underline{\Delta}=\frac{p_2-(1-\delta)\mu\pm[p_1-(1-\delta)\mu]\sqrt{\frac{p_1-\underline{c_1}}{p_2-\underline{c_2}}}}{1-\delta\left(1\pm\sqrt{\frac{p_1-\underline{c_1}}{p_2-\underline{c_2}}}\right)}$.
Thus in the relevant range $\Delta\in\left(\underline{\Delta},\overline{\Delta}\right]$ the optimal time has an interior solution.
Q.E.D.

Proof of Proposition 3

a) In case of known value added of the new product, the ratio $\frac{T^*}{T_N^*}>1$ if $\frac{1-p_1}{1-p_1-\delta(1+\Delta-p_2)}\frac{\left(p_1-\underline{c_1}\right)(\mu-p_1)^2-\left(p_2-\underline{c_2}\right)(\mu+\Delta-p_2)^2}{\left(p_1-\underline{c_1}\right)\left(\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}\right)^2-\left(p_2-\underline{c_2}\right)(\mu+\Delta-p_2)^2}>1$ which holds since $(\mu-p_1)^2>\left(\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}\right)^2$ for this model as $\Delta>(p_2-p_1)$. Note that in case $\left(\frac{\mu+\Delta-p_2}{\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}}\right)^2>\frac{p_1-c_1}{p_2-c_2}>\left(\frac{\mu+\Delta-p_2}{\mu-p_1}\right)^2>1$, T_{IN}^* may have an interior solution while T_I^* will not.
b) The partial derivative of the optimal time with respect to the quality enhancement, Δ is given by $\frac{\partial T_I^*}{\partial\Delta}=\frac{\frac{\partial x_1\left(T_I^*\right)}{\partial\Delta}}{\frac{\partial x_1\left(T_I^*\right)}{\partial T_I^*}}$ which is positive if $\frac{\partial x_1\left(T_I^*\right)}{\partial\Delta}>0$.

$$\begin{aligned}\frac{\partial x_1\left(T_I^*\right)}{\partial\Delta} &= T_I^*\left(\frac{1}{\mu+\Delta-p_2}+\frac{1}{\Delta-p_2+p_1}+2\frac{\delta\frac{p_1-\underline{c_1}}{1-\delta}\left[\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}\right]+\left(p_2-\underline{c_2}\right)(\mu+\Delta-p_2)}{\left(p_1-\underline{c_1}\right)\left[\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}\right]^2-\left(p_2-\underline{c_2}\right)(\mu+\Delta-p_2)^2}\right)\\ &> 0\end{aligned}$$

Here all the individual terms are positive.
c) The partial derivative of the optimal time of introduction with respect to the true mean quality μ yields $\left[\mu - p_1 - \delta\frac{\Delta-(p_2-p_1)}{1-\delta}\right] \frac{\partial T_I^*}{\partial \mu} = n_0 \left[\frac{1}{\mu+\Delta-p_2} + \frac{1}{\mu-1} - 2B\right] - T_I^*$ where $B = \frac{(p_1-\underline{c_1})\left(\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}\right)-(p_2-\underline{c_2})(\mu+\Delta-p_2)}{(p_1-\underline{c_1})\left(\mu-p_1-\delta\frac{\Delta-(p_2-p_1)}{1-\delta}\right)^2-(p_2-\underline{c_2})(\mu+\Delta-p_2)^2}$. To prove that $\frac{\partial T_I^*}{\partial \mu} < 0$ it is sufficient to prove that the term inside the brackets is less than zero. Since $\frac{1}{\mu+\Delta-p_2} + \frac{1}{\mu-1} < 2$, we need to show that $B > 1$. The latter holds since $\mu + \Delta - p_2 > \mu - p_1 - \delta\frac{\Delta-(p_2-p_1)}{1-\delta}$ and the condition from the proof of lemma 1a).
Q.E.D.

Proof of Proposition 4

From the first order conditions $\frac{\partial \pi_I(R_I,R_E^*)}{\partial R_I} = 0$ and $\frac{\partial \pi_I(R_I^*,R_E)}{\partial R_E} = 0$ (refer Equations 15 and 16), we have

$$\frac{\partial h(R_I)}{\partial R_I}\left[(p_1-\underline{c_1})\left\{\int_0^T e^{-r\tau}\dot{x}_1(\tau)\,d\tau + \int_T^\infty e^{-r\tau}\dot{x}_{1A}(\tau)\,d\tau\right\} + (p_2-\underline{c_2})\int_T^\infty e^{-r\tau}\dot{x}_2 d\tau\right]$$
$$-\frac{\partial h(R_I)}{\partial R_I}(p_1-\underline{c_1})\int_0^\infty e^{-r\tau}\dot{x}_1(\tau)\,d\tau = 1, \text{ and}$$
$$\frac{\partial h(R_E)}{\partial R_E}(p_2-\underline{c_2})\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau = 1.$$

which solve respectively for R_I^* and R_E^*.
Considering the specific functional form $h(R_\theta) = 1 - e^{-R_\theta}$, we have $h'(R_\theta) = e^{-R_\theta}$. The first order conditions simplify as

$$\begin{aligned} e^{R_I} &= (p_1-\underline{c_1})\left\{\int_0^T e^{-r\tau}\dot{x}_1(\tau)\,d\tau + \int_T^\infty e^{-r\tau}\dot{x}_{1A}(\tau)\,d\tau\right\} + (p_2-\underline{c_2})\int_T^\infty e^{-r\tau}\dot{x}_2 d\tau \\ &\quad -e^{-R_E}(p_1-\underline{c_1})\int_0^T e^{-r\tau}\dot{x}_1(\tau)\,d\tau \\ e^{R_E} &= (p_2-\underline{c_2})\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau \end{aligned}$$

from which we get the incumbent's reaction function

$$\begin{aligned} R_I^*(R_E) &= \ln\left[(p_1-\underline{c_1})\left\{\int_0^T e^{-r\tau}\dot{x}_1(\tau)\,d\tau + \int_T^\infty e^{-r\tau}\dot{x}_{1A}(\tau)\,d\tau\right\}\right. \\ &\quad \left. + (p_2-\underline{c_2})\int_T^\infty e^{-r\tau}\dot{x}_2 d\tau - e^{-R_E}(p_1-\underline{c_1})\int_0^\infty e^{-r\tau}\dot{x}_1(\tau)\,d\tau\right]. \end{aligned}$$

Note that and the Nash equilibrium investments in R&D are given by

$$R_I^* = \ln\left[\left(p_1-\underline{c_1}\right)\left\{\int_0^T e^{-r\tau}\dot{x}_1(\tau)\,d\tau+\int_T^\infty e^{-r\tau}\dot{x}_{1A}(\tau)\,d\tau\right\}\right.$$
$$\left.+\left(p_2-\underline{c_2}\right)\int_T^\infty e^{-r\tau}\dot{x}_2 d\tau-\frac{\left(p_1-\underline{c_1}\right)\int_0^\infty e^{-r\tau}\dot{x}_1(\tau)\,d\tau}{\left(p_2-\underline{c_2}\right)\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau}\right], \tag{38}$$

$$R_E^* = \ln\left[\left(p_2-\underline{c_2}\right)\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau\right]. \tag{39}$$

The condition for $R_I^* > R_E^*$ using the Equations 31 and 32 is given by

$$\left(p_1-\underline{c_1}\right)\left\{\int_0^T e^{-r\tau}\dot{x}_1(\tau)\,d\tau+\int_T^\infty e^{-r\tau}\dot{x}_{1A}(\tau)\,d\tau\right\}-\left(p_2-\underline{c_2}\right)\int_0^T e^{-r\tau}\dot{x}_2 d\tau > \frac{\left(p_1-\underline{c_1}\right)\int_0^\infty e^{-r\tau}\dot{x}_1(\tau)\,d\tau}{\left(p_2-\underline{c_2}\right)\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau}, \tag{40}$$

Note that $\left(p_1-\underline{c_1}\right)\left\{\int_0^T e^{-r\tau}\dot{x}_1(\tau)\,d\tau+\int_T^\infty e^{-r\tau}\dot{x}_{1A}(\tau)\,d\tau\right\}-\left(p_2-\underline{c_2}\right)\int_0^T e^{-r\tau}\dot{x}_2 d\tau$ is the incumbent's loss if it introduces the new product immediately at time $t=0$ instead of $t=T$ when it wins, $\left(p_1-\underline{c_1}\right)\int_0^\infty e^{-r\tau}\dot{x}_1 d\tau$ is the incumbent's profit if the new product is never introduced and $\left(p_2-\underline{c_2}\right)\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau$ is the profit from launching the new product immediately (at $t=0$).
Q.E.D.

Proof of Proposition 5

Follows from the partial derivative of the difference of R_I^* and R_E^* from Equations 31 and 32, i.e., $\frac{\partial\left(R_I^*-R_E^*\right)}{\partial T} \geqslant 0$. Note that if $\frac{\partial R_I^*}{\partial T} \geqslant 0$ then also $\frac{\partial\left(R_I^*-R_E^*\right)}{\partial T} \geqslant 0$. But $\frac{\partial R_I^*}{\partial T} = e^{-rT}$ $\frac{\left(p_1-\underline{c_1}\right)\left[\dot{x}_1(T)-\dot{x}_{1A}(T)\right]-\left(p_2-\underline{c_2}\right)\dot{x}_2(T)}{\left(p_1-\underline{c_1}\right)\left\{\int_0^T e^{-r\tau}\dot{x}_1(\tau)d\tau+\int_T^\infty e^{-r\tau}\dot{x}_{1A}(\tau)d\tau\right\}+\left(p_2-\underline{c_2}\right)\int_T^\infty e^{-r\tau}\dot{x}_2 d\tau-\frac{\left(p_1-\underline{c_1}\right)\int_0^\infty e^{-r\tau}\dot{x}_1(\tau)d\tau}{\left(p_2-\underline{c_2}\right)\int_0^\infty e^{-r\tau}\dot{x}_2 d\tau}} \geqslant 0$ if $\left(p_1-\underline{c_1}\right)$ $\left[\dot{x}_1(T)-\dot{x}_{1A}(T)\right] \geqslant \left(p_2-\underline{c_2}\right)\dot{x}_2(T)$ and Condition 40 holds.
Q.E.D.

Proof of Lemma 2

Note that if it wins the market for the new product, the incumbent also decides the timing of introduction of the new product which is given by

$$T_U^* = \arg\max\left\{\left(p_1-\underline{c_1}\right)\left\{\int_0^T e^{-r\tau}\dot{x}_1(\tau)\,d\tau+\int_T^\infty e^{-r\tau}\dot{x}_{1A}(\tau)\,d\tau\right\}+\left(p_2-\underline{c_2}\right)\int_T^\infty e^{-r\tau}\dot{x}_2 d\tau\right\}. \tag{41}$$

We can therefore obtain the first order condition (FOC),

$$\left(p_1-\underline{c_1}\right)\left[\dot{x}_1(T)-\dot{x}_{1A}(T)\right]-\left(p_2-\underline{c_2}\right)\dot{x}_2(T)=0. \tag{42}$$

Under rational expectations ($p_{2e} = p_2$) and using Equations 27, **??** and 26, we get

$$\begin{aligned}
& \left(p_1 - \underline{c_1}\right)\left[\left(p_2 - p_1\right)\frac{\mu - p_1}{n_0} x_1(T) - \frac{\mu - p_1}{n_0}\frac{x_{1A}^2(T)}{x_{1A}(T) + x_2(T)} + \frac{\nu - p_2 + p_1}{k_0}\left[x_{1A}(T) + x_2(T)\right] x_2(T)\right] \\
= \; & \left(p_2 - \underline{c_2}\right)\left[\frac{\mu - p_1}{n_0}\frac{x_{1A}(T)\, x_2(T)}{x_{1A}(T) + x_2(T)} + \frac{\nu - p_2 + p_1}{k_0}\left[x_{1A}(T) + x_2(T)\right] x_2(T)\right].
\end{aligned}$$

Simplifying further we get

$$\begin{aligned}
& \frac{\mu - p_1}{n_0}\frac{k_0}{\nu - p_2 + p_1}\left[\left(p_1 - \underline{c_1}\right)\left\{\left(p_2 - p_1\right) x_1(T) - \frac{x_{1A}^2(T)}{x_{1A}(T) + x_2(T)}\right\} - \left(p_2 - \underline{c_2}\right)\frac{x_{1A}(T)\, x_2(T)}{x_{1A}(T) + x_2(T)}\right] \\
= \; & \left[\left(p_2 - \underline{c_2}\right) - \left(p_1 - \underline{c_1}\right)\right]\left[x_{1A}(T) + x_2(T)\right] x_2(T).
\end{aligned}$$

Rearranging and substituting the initial conditions we get

$$\begin{aligned}
& \frac{\mu - p_1}{n_0}\frac{k_0}{\nu - p_2 + p_1}\left[\left(p_1 - \underline{c_1}\right)\left(p_2 - p_1 - \frac{1}{2 - p_2 + p_1}\right) - \left(p_2 - \underline{c_2}\right)\frac{1 - p_2 + p_1}{2 - p_2 + p_1}\right] \\
= \; & \left[\left(p_2 - \underline{c_2}\right) - \left(p_1 - \underline{c_1}\right)\right] x_{1A}(T)\left(2 - p_2 + p_1\right)\left(1 - p_2 + p_1\right).
\end{aligned}$$

Simplifying further we get

$$x_{1A}(T) = \frac{\mu - p_1}{n_0}\frac{k_0}{\nu - p_2 + p_1}\frac{1}{\left(2 - p_2 + p_1\right)^2}\frac{\left(p_1 - \underline{c_1}\right)\left(1 - p_2 + p_1\right) + p_2 - \underline{c_2}}{\left(p_1 - \underline{c_1}\right) - \left(p_2 - \underline{c_2}\right)}.$$

Solving, we get:

$$T_U^* = \frac{n_0}{\mu - p_1}\ln\left[\frac{\mu - p_1}{n_0}\frac{k_0}{\nu - p_2 + p_1}\frac{1}{1 - p_1}\frac{1}{p_2 - p_1}\frac{1}{\left(2 - p_2 + p_1\right)^2}\frac{\left(p_1 - \underline{c_1}\right)\left(1 - p_2 + p_1\right) + p_2 - \underline{c_2}}{p_1 - \underline{c_1} - \left(p_2 - \underline{c_2}\right)}\right]. \tag{43}$$

The condition for T_U^* to exist is $p_1 - \underline{c_1} > p_2 - \underline{c_2}$ given that the condition $1 + \frac{p_2 - \underline{c_2}}{p_1 - \underline{c_1}} > p_2 - p_1$ always holds under the assumptions of the model. We show that $\pi_I(T)$ is concave in $[0, \infty)$ as long as T_U^* exists and therefore it is a maximum. The condition that $\pi_I(T)$ is concave is given as

$$\vartheta \pi_I(0) + (1 - \vartheta)\pi_I(\infty) \leqslant \pi_I(\vartheta .0 + (1 - \vartheta)\infty)$$

for $0 < \vartheta < 1$. Simplifying, we get

$$\left(p_1 - \underline{c_1}\right)\int_0^\infty e^{-r\tau}\dot{x}_{1A}(\tau)\, d\tau \leqslant \left[p_1 - \underline{c_1} - \left(p_2 - \underline{c_2}\right)\right]\int_0^\infty e^{-r\tau}\dot{x}_1(\tau)\, d\tau$$

which holds for any t if

$$\left(p_1 - \underline{c_1}\right)\dot{x}_{1A}(t) \leqslant \left[p_1 - \underline{c_1} - \left(p_2 - \underline{c_2}\right)\right]\dot{x}_1(t).$$

Using the first order condition (Equation 42) for any T, the above condition simplifies to

$$\left(p_2 - \underline{c_2}\right)\left[\dot{x}_1(T) - \dot{x}_2(T)\right] \leqslant 0 \text{ or } \dot{x}_2(T) \geqslant \dot{x}_1(T)$$

Using Equations 27, **??** and 26, the condition for concavity of π_I becomes

$$\begin{aligned} x_{1A}(T) &\geqslant \frac{\mu-p_1}{n_0}\frac{k_0}{\nu-p_2+p_1}\frac{1}{2-p_2+p_1}\left(\frac{p_2-p_1}{1-p_2+p_1}-\frac{1}{2-p_2+p_1}\right) \\ \Rightarrow\ T &\geqslant \frac{n_0}{\mu-p_1}\ln\left[\frac{\mu-p_1}{n_0}\frac{k_0}{\nu-p_2+p_1}\frac{1}{1-p_1}\frac{\frac{1}{1-p_2+p_1}-\frac{1}{(2-p_2+p_1)(p_2-p_1)}}{2-p_2+p_1}\right] \end{aligned}$$

Comparing with T_U^* (Equation 43), we can see that the above condition holds as long as

$$\left(p_1-\underline{c_1}\right)\left[1-2\left(p_2-p_1\right)\right]+\left(p_2-\underline{c_2}\right)\left(p_2-p_1\right)>0$$

a sufficient condition for which is $p_2-p_1<1/2$. Thus T_U^* is a maximum if $p_2-p_1<1/2$.
Q.E.D.
Proof of Proposition 6

a) In case of unknown value added of the new product, when consumers do not expect the new product, the initial conditions at $t=T$ for the current product changes to $x_{1A}(T)=(1-p_1)\exp\left[\frac{\mu-p_1}{n_0}T\right]$. The initial condition for the new product remains $x_2(T)=x_{1A}(T)(1-p_2+p_1)$ Using these conditions, we can show that the first order condition (equation 42) reduces to

$$\begin{aligned} & \left(p_1-\underline{c_1}\right)\left[\frac{\mu-p_1}{n_0}\frac{1-p_2+p_1}{2-p_2+p_1}-\frac{\nu-p_2+p_1}{k_0}\left(2-p_2+p_1\right)x_{1A}(T)\left(1-p_2+p_1\right)\right] \\ = & \left(p_2-\underline{c_2}\right)\left[\frac{\mu-p_1}{n_0}\frac{1-p_2+p_1}{2-p_2+p_1}+\frac{\nu-p_2+p_1}{k_0}\left(2-p_2+p_1\right)\left(1-p_2+p_1\right)x_{1A}(T)\right] \end{aligned}$$

Rearranging, simplifying and solving for T, we get

$$\begin{aligned} \exp\left[\frac{\mu-p_1}{n_0}T\right] &= \frac{1}{1-p_1}\frac{\mu-p_1}{n_0}\frac{k_0}{\nu-p_2+p_1}\frac{1}{\left(2-p_2+p_1\right)^2}\frac{\left(p_1-\underline{c_1}\right)-\left(p_2-\underline{c_2}\right)}{\left(p_2-\underline{c_2}\right)+\left(p_1-\underline{c_1}\right)} \\ \Rightarrow T_{UN}^* &= \frac{n_0}{\mu-p_1}\ln\left[\frac{1}{1-p_1}\frac{\mu-p_1}{n_0}\frac{k_0}{\nu-p_2+p_1}\frac{1}{\left(2-p_2+p_1\right)^2}\frac{\left(p_1-\underline{c_1}\right)-\left(p_2-\underline{c_2}\right)}{\left(p_2-\underline{c_2}\right)+\left(p_1-\underline{c_1}\right)}\right]. \end{aligned}$$

Note that $\frac{T_U^*}{T_{UN}^*}>1$ if

$$\left[\left(p_1-\underline{c_1}\right)\left(1-p_2+p_1\right)+p_2-\underline{c_2}\right]\left[\left(p_2-\underline{c_2}\right)+\left(p_1-\underline{c_1}\right)\right]>\left[\left(p_1-\underline{c_1}\right)-\left(p_2-\underline{c_2}\right)\right]^2\left(p_2-p_1\right).$$

This condition simplifies as

$$\left[1-2\left(p_2-p_1\right)\right]\left(\frac{p_1-\underline{c_1}}{p_2-\underline{c_2}}\right)^2+\left(2+p_2-p_1\right)\frac{p_1-\underline{c_1}}{p_2-\underline{c_2}}+1-p_2+p_1>0.$$

which always holds if $p_2-p_1<1/2$ (sufficient condition) which is also a sufficient condition for T_U^* to be a maximum and hence assumed to hold.
b) The partial derivative of the optimal time with respect to the quality enhancement, ν is given by

$$\frac{\partial T_U^*}{\partial \nu}=-\frac{n_0}{\mu-p_1}\frac{1}{\nu-p_2+p_1}<0.$$

c) The partial derivative of the optimal time of introduction with respect to the true mean quality yields

$$\frac{\partial T_U^*}{\partial \mu} = n_0 \frac{1 - \ln\left[\frac{\mu - p_1}{n_0} \frac{k_0}{\nu - p_2 + p_1} \frac{1}{1 - p_1} \frac{1}{p_2 - p_1} \frac{1}{(2 - p_2 + p_1)^2} \frac{\left(p_1 - \underline{c_1}\right)(1 - p_2 + p_1) + p_2 - \underline{c_2}}{p_1 - \underline{c_1} - \left(p_2 - \underline{c_2}\right)}\right]}{(\mu - p_1)^2}$$

which is positive if $\mu < \bar{\mu}$ or negative if $\mu > \bar{\mu}$ where $\bar{\mu} = p_1 +$ $2.72 n_0 \frac{p_1 - \underline{c_1} - \left(p_2 - \underline{c_2}\right)}{\left(p_1 - \underline{c_1}\right)(1 - p_2 - p_1) + p_2 - \underline{c_2}}$ $(2 - p_2 + p_1)^2$ $(p_2 - p_1)$ $(1 - p_1)$ $\frac{\nu - p_2 + p_1}{k_0}$.

Q.E.D.