Durable Goods Monopoly with Endogenous Innovation*

Jae Nahm  
Department of Economics  
Hong Kong University of Science and Technology  
Clearwater Bay, Kowloon  
Hong Kong  

E-mail: jnahm@ust.hk,  
Tel: 852-2358-7626  

Oct 2003  

*I am grateful to Adam Brandenburger, Drew Fudenberg, Rena Henderson, Eric Maskin, and Tomas Sjostrom for their helpful comments and advice. The responsibility for errors lies with me.
Abstract

While selling an existing product, a durable-goods monopolist may develop a new, improved product. The firm must consider the interaction between its intertemporal pricing and R&D decisions. The interactions show a sharp dichotomy depending on pricing regimes. When it is optimal for the firm to continue to sell the old model along with the new model, the interactions disappear. However, when it is optimal for the firm to discontinue the sale of the old model after introducing the new model, the firm will face a time-inconsistency problem in its R&D decision.

*Keywords:* Durable Goods Monopoly; Planned Obsolescence; Endogenous Innovation; Coasian Dynamics

*JEL Classification:* D42; L12
1 Introduction

While selling a current product, a firm continues to do R&D in order to improve the product and, sequentially, introduces a new, improved product. For example, Intel keeps developing a faster, more advanced CPU Chip. Electronic companies upgrade their models yearly, and software companies frequently offer upgrades of their software.

In this article, we investigate how a durable-goods monopolist’s pricing decision interacts with its R&D activity. In a durable-goods market, there are interesting interactions between old and new products. First, consumers, knowing that a firm will introduce a new product in the near future, are reluctant to pay a high price for a current product and may choose to wait for the new product instead. The expectation of the new product has a negative influence on the sales of the old product. Second, even though the firm introduces the new product, consumers who have bought the old product may continue to use it instead of buying the new product. The outstanding stock of already-purchased old products has an influence on the price of the new product. Given these interactions between the old and new products, the firm solves for both its optimal intertemporal pricing and R&D decisions.

In an interesting article, Waldman (1996) points out that a durable-goods monopolist faces a time-inconsistency problem concerning its R&D decision. In Waldman, a durable-goods monopolist sells a low-quality product in period one, invests in R&D for a high-quality product, and sells the high-quality product in period two. The expectation of the high-quality product has a negative impact on the sales of the low-quality product. Therefore, while it is still selling the low-quality product, the firm wants to convince consumers that it will not invest in R&D for the high-quality product. However, after having sold its low-quality product, the firm has a different incentive and develops the high-quality product. Consumers, knowing this, are reluctant to pay a high price for the low-quality product, and, as a result, the firm is forced to charge a low price in period one. From the standpoint of the monopolist’s own profitability, the firm’s incentive to introduce the new product (or to invest in R&D for the new product) is too high. The firm would be better off if it could commit not to undertake the R&D activity. This leads to a
time-inconsistency problem in the monopolist’s R&D decision.

Waldman (1996) assumes a simple demand structure: there are two types of consumers, high and low types; the low type values the low-quality product so low that the firm never has an incentive to sell its output to the low type. Without the high-quality product, the firm will be inactive in period two, and the price of the low-quality good does not change in period two. That is, the standard Coasian dynamics are assumed away. The price of the low-quality product in period two will drop only if the firm introduces the high-quality product. The assumption is essential in deriving the time-inconsistency problem in Waldman. Instead, suppose that in the two-type model, the low-type consumers are attractive enough that the firm will optimally lower the price of the low-quality product in period two in order to sell the low-quality product to the low-type consumers. That is, whether or not the firm introduces the high-quality product, the price of the low-quality product drops in period two. An important question is: how much does the advent of the high-quality product depress the price of the low-quality product relative to the standard Coasian case without the new product? If the magnitudes of these price drops in the two cases are exactly the same, the price path of the low-quality product is unaffected by the arrival of the high-quality product, the firm’s pricing decision becomes separate from its R&D decision, and the firm does not face the time-inconsistency problem in its R&D decision.

In the two-type model, in which the firm optimally sells the old product to the low type in period two, the marginal type (or the marginal consumer) of the old product in period two is always the low type, and the price of the old product is the same whether or not the firm introduces the new product. The time-inconsistency problem in Waldman (1996) does not arise in this case. Our article investigates the interactions between old and new products with a more generalized demand structure, a continuum of consumer types. In the continuous-type model, the Coasian dynamics always exist, and the firm can choose its optimal marginal type (or its price) continuously. Contrary to the two-type model, the firm’s optimal second-period marginal type of the low-quality product is different, depending on the second-period pricing regime, such as net-sales, inactive, and buy-back regimes. As a result, the interactions
between R&D and pricing decisions are quite different, depending on second-period pricing regimes.

In the net-sales case, in which a firm optimally continues to sell an old product along with a new product, the second-period price of the old product is the same whether or not the firm introduces the new product. Thus, the price path of the old product is unaffected by the arrival of the new product. Also, the firms’ optimal level of R&D investment for the new product does not depend on the past sales of the old product. As a result, the firm can separate its pricing decision from its R&D decision. Intel’s CPU chip provides a good example of this case. In 1982, while it was selling the 8088 and 8086 chips, Intel introduced the 80286 chip. The advent of the 80286 did not terminate the product life of the 8088 and 8086 chips. Intel remained active in both chips and, in fact, the number of units shipped of the 8086 and 8088 peaked in 1987. The life cycle of the 80286 had a similar pattern. Even after the advent of the 80386DX series in 1985, the 80286 remained Intel’s main leading product. The products followed their own product life cycles even after Intel introduced a new chip.

However, after introducing a new product, a firm may be inactive in an old product market or may purchase back the old product. In these cases, the arrival of the new product depresses the price of the old product more than the standard Coasian dynamics do. Thus, the price path of the old product depends on the advent of the new product. As a result, we have the time-inconsistency problem in the monopolist’s R&D decision.

This article shows that in the continuous-type model, the interactions between old and new products depends on second-period pricing regimes. In markets such as TVs or VCRs, where companies typically continue to sell old models even after introducing new models, there is no interaction between old and new products. However, in markets such as autos, in which firms typically discontinue the sale of older models after introducing new models, we expect to see the time-inconsistency problem.

Related Literature

The durable-goods monopolist’s commitment problem in pricing decisions dates back to Coase (1972). Bulow (1986) argues that a durable-goods mo-
nopolist may build a level of durability and that planned obsolescence is more than a matter of physical durability. Choi (1994) and Waldman (1993) analyze a durable-goods monopolist’s compatibility decision in terms of planned obsolescence. They show that the monopolist faces a time-inconsistency problem concerning its compatibility decision.

More recently, Lee and Lee (1998) and Fudenberg and Tirole (1998) studied monopoly pricing of successive generations of a durable good. However, these papers focus on the monopolist’s pricing decision rather than on its incentive to innovate, assuming exogenously given technological progress.⁵

Fishman and Rob (2000) investigate a durable-goods monopolist’s R&D incentive in a model with identical consumers under the assumption that a product forms a technical base for a next product. Since consumers pay only for an incremental quality improvement, the monopolist as compared with the social planner innovates less frequently and invests less.

The remainder of the paper is organized as follows. Section 2 describes the model and imposes several parameter restrictions. Section 3 presents a complete analysis. Section 4 discusses the two-type model and the zero-unit-production-cost case. Section 5 concludes.

2 A Model

In a two-period model, consumers and a durable-goods monopolist have a common discount factor $\delta$. The market demand consists of a continuum of nonatomic buyers.⁶ Buyers have different preferences with respect to products’ quality. Their preferences are represented by $\theta$, and $\theta$ is uniformly distributed along $[0,1]$.⁷ A type-$\theta$ consumer has per-period utility $\theta V + I$, where $I$ is her net income, and $V$ is a quality index of a product.

In period one, the monopolist produces a low quality good, product $L$. Between periods one and two, the firm can make an R&D investment in a new, high-quality generation of the good, product $H$. The quality indexes for products $L$ and $H$ are $V_L$ and $V_H$, respectively, and $V_H > V_L = 1$.

When the firm invests $R$ in R&D, $d(R)$ denotes the probability that the R&D will be successful, and $C(R)$ denotes the cost of R&D. It is assumed
that \( d(0) = 0, \quad d'(0) = \infty, \quad d'(R) > 0 \) and \( d''(R) < 0 \) and that \( C(R) \) is convex.

In period two, the monopolist can produce both products \( L \) and \( H \) if the R&D is successful. Otherwise, the firm can sell only product \( L \). Products \( L \) and \( H \) are produced at the cost \( c_L \) and \( c_H \), respectively. To limit the number of cases, we assume that \( V_H - V_L > c_H \), that is, the highest type’s willingness to pay for upgrading is larger than the unit cost \( c_H \).

The firm cannot commit either to future prices or to a level of R&D expenditure. There is a frictionless secondhand market for product \( L \) in period two. In period two consumers can sell product \( L \) at the secondhand market after buying product \( H \). Because of the frictionless secondhand market, a consumer’s second-period consumption decision is not affected by whether or not she bought product \( L \) in period one.

3 Analysis of the Monopoly R&D Decision

The firm makes the following decisions. How many units of product \( L \) should it sell in period one? How much should it invest in R&D? How many units of products \( H \) and \( L \) should it sell in period two, if the R&D is successful? And how many units of product \( L \) should it sell in period two, if the R&D fails? The objective function of the firm is as follows.

\[
\Pi = \Pi_1 + \delta E(\Pi_2) \\
= (p_1(x) - c_L)x + \delta \left[ d(R)\Pi_2^s(x) + (1 - d(R))\Pi_2^f(x) \right] - \delta C(R),
\]

where subscript \( i \) denotes period \( i \), and \( x \) denotes the first-period sales of product \( L \). \( \Pi_2^s(x) \) and \( \Pi_2^f(x) \) denote the firm’s second-period profits with product \( H \) and without product \( H \), respectively.

The first-period price of product \( L \) is the sum of the rental price in period one and the expected second-period price. When the firm sells \( x \) units of product \( L \), the rental price in period one is \( 1 - x \).\(^8\) The second-period price of product \( L \) may depend on whether or not the firm introduces product \( H \).

\[
p_1(x) = (1 - x) + \delta E[p_L(x)] = (1 - x) + \delta [d(R)p_L^s + (1 - d(R))p_L^f]
\]
where \( p^*_L \) and \( p^f_L \) denote the second-period price of product \( L \) with product \( H \) and without product \( H \), respectively.

We will investigate the interactions between the first-period sales of product \( L \) and the R&D investment level: how the possibility that the firm will introduce product \( H \) affects the sales of product \( L \) in period one; how the sale of product \( L \) in period one affects the firm’s optimal R&D level for product \( H \).

As usual, this paper starts by solving backward from the second period. The equilibrium concept is SPNE.

### 3.1 Period Two

The firm has already sold \( x \) units of product \( L \) in period one. If R&D fails, the firm can sell only product \( L \). The firm maximizes its profits by choosing the cutoff point \( \theta_L \), i.e., consumers whose types are higher than \( \theta_L \) use product \( L \). When the firm sets the cutoff point at \( \theta_L \), the firm sells \((1 - \theta_L - x)\) units of product \( L \) in period two.

\[
\Pi^f_2 = (1 - \theta_L - x)(\theta_L - c_L)
\]  

(1)

The firm’s optimal \( \theta^*_L \) is \( \frac{1-x+c_L}{2} \), and the price of the old product in period two is \( \frac{1-x+c_L}{2} \).

If R&D is successful, the firm introduces product \( H \). The second-period market outcome is summarized by two cutoffs, \( \theta_L \) and \( \theta_H \): types between \( \theta_H \) and \( \theta_L \) consume product \( L \); types \( \theta \geq \theta_H \) consume product \( H \). The prices of products \( L \) and \( H \) are directly related to the two cutoff points, \( p_L = V_L\theta_L \), and \( p_H = V_L\theta_L + (V_H - V_L)\theta_H \). The monopolist is considered as solving the optimization problem by choosing the two cutoff points. \( \theta^*_H - \theta^*_L \) denotes the firm’s intended number of product \( L \) in period two. The firm can sell both products or only product \( H \). For instance, when \( \theta^*_H - \theta^*_L \) is larger than \( x \), the firm provides additional \((\theta^*_H - \theta^*_L - x)\) units of product \( L \) in period two. When \( \theta^*_H - \theta^*_L = x \), the firm is inactive in product \( L \). When \( \theta^*_H - \theta^*_L \) is less than \( x \), the firm buys back some amount of product \( L \). As Fudenberg and Tirole (1998) show, the monopolist’s optimal second-period
policy on product \( L \) depends on the size of the quality improvement, the cost difference, and the first-period sales: the monopolist sells additional units of product \( L \) if \( x \leq \frac{c_H - c_L}{V_H - V_L} \); the monopolist buys back product \( L \) if \( x \geq \frac{c_H}{V_H - V_L} \); the monopolist is inactive on the product \( L \) market otherwise.

The profit functions are as follows,

\[
\begin{align*}
\Pi_{\text{netsales}}^2 & = (\theta_H - \theta_L - x)(p_L - c_L) + (1 - \theta_H)(p_H - c_H) \\
\Pi_{\text{buybacks}}^2 & = -(x - (\theta_H - \theta_L))p_L + (1 - \theta_H)(p_H - c_H) \\
\Pi_{\text{inactive}}^2 & = (1 - \theta_H)(p_H - c_H)
\end{align*}
\]

**Net sales**

We can rearrange the profit function of net sales.

\[
\Pi_{\text{netsales}}^2 = (\theta_H - \theta_L - x)(V_L\theta_L - c_L) + (1 - \theta_H)[V_L\theta_L + (V_H - V_L)\theta_H - c_H]
\]

\[
= (1 - \theta_L - x)(V_L\theta_L - c_L) + (1 - \theta_H)[(V_H - V_L)\theta_H - (c_H - c_L)] \quad (2)
\]

The first term of equation (2) is exactly equation (1). The second term of equation (2) does not have \( \theta_L \). Therefore, equations (1) and (2) yield the same optimal level of \( \theta_L^* \)

\[
\theta_L^* = \frac{1 - x + c_L}{2}
\]

**Lemma 1.** When it is optimal for the firm to be a net seller of product \( L \), the price of product \( L \) in period two does not depend on whether or not the firm introduces product \( H \).

When the firm introduces product \( H \), it reduces the price of product \( L \). However, even without the advent of product \( H \), the firm, by reducing the price of product \( L \), sells product \( L \) to the residual consumers. Therefore, whether or not the firm introduces the new product, the price of product \( L \) will drop. The magnitudes of these price drops are exactly the same. Therefore, the second-period price of product \( L \) is not affected by product \( H \).
**Buybacks and Inactive**

Consider the other cases - buybacks and inactivity. We can rearrange the profit function of buybacks.

\[
\Pi_2^{\text{buybacks}} = -(x - \theta_H - \theta_L)V_L\theta_L + (1 - \theta_H)[V_L\theta_L + (V_H - V_L)\theta_H - c_H] \\
= (1 - \theta_L - x)V_L\theta_L + (1 - \theta_H)[(V_H - V_L)\theta_H - c_H]
\]

(3)

The first order condition provides

\[
\theta^*_L = \frac{1 - x}{2}
\]

For the case of buy-backs, \(p_L\) becomes \(\frac{1-x}{2}\), which is lower than \(\frac{1-x+c_L}{2}\). That is, the price of product \(L\) drops more when the firm introduces product \(H\) than when the firm does not. Suppose that \(c_L\) is zero, which is a good approximation of the software industry. Then, we have \(p_L^{\text{netsales}}(x) = \frac{1-x}{2} = p_L^{\text{buybacks}}\), and \(p_L\) does not depend on the advent of product \(H\). We will make some comments on the case of zero-unit-production-cost in section 4.2

When the firm is inactive, \(\theta_H = \theta_L + x\). Since \(\theta_H\) is automatically determined by \(\theta_L\), the firm maximizes its profit function by choosing \(\theta_L\).

\[
\Pi_2^{\text{inactive}} = (1 - \theta_H)[p_H - c_H] \\
= (1 - \theta_L - x)[(V_H - V_L)(\theta_L + x) + V_L\theta_L - c_H]
\]

The first order condition provides

\[
\theta^*_L = \frac{1}{2} + \frac{c_H + x}{2V_H} - x
\]

We find that \(p_L^{\text{netsales}}(x) = \frac{1-x+c_L}{2} > p_L^{\text{inactive}}(x) > p_L^{\text{buybacks}}\) as long as \(c_L > 0\). When the firm either is optimally inactive or buys back product \(L\), the advent of product \(H\) depresses the price of product \(L\) more than the standard Coasian dynamics do.

Lemma 2. When it is optimal for the firm to buy back or to be inactive in product \(L\), the advent of product \(H\) depresses \(p_L\) more than the standard Coasian dynamics do.
3.2 R&D Decision

After selling $x$ units of product $L$ in period one, the firm undertakes an R&D activity to develop product $H$. Since potential buyers may extend their use of product $L$, the outstanding stock of product $L$ puts a constraint on the price of product $H$. Thus, the firm’s R&D incentive for product $H$ may depend on the amount of product $L$ the firm has sold in period one.

Between periods one and two, the firm maximizes the following objective function by choosing its R&D level.

$$d(R)\Pi_2^s(x) + (1 - d(R))\Pi_2^f(x) - C(R)$$

The optimal level of R&D investment ($R^*$) is such that

$$d'(R^*)(\Pi_2^s(x) - \Pi_2^f(x)) = C'(R^*). \tag{4}$$

Since $d(R)$ is concave and $C(R)$ is convex, there is a unique $R$ satisfying equation (4). The optimal level of R&D investment depends on the profit difference between product portfolios with and without product $H$.

Net sales

As the comparison between equations (1) and (2) shows, the profit difference $(\Pi_2^s(x) - \Pi_2^f(x))$ is just the second term of equation (2), which is independent of $x$. Therefore, the optimal R&D level does not depend on $x$.

Lemma 3. In the case of net sales, the optimal level of R&D investment does not depend on the number of product $L$ that has been sold in period one.

Buybacks and Inactive

When the firm either is inactive or buys back product $L$ in period two, the profit difference $(\Pi_2^s(x) - \Pi_2^f(x))$ is a decreasing function of $x$. Therefore, the optimal level of R&D investment decreases in $x$.

Lemma 4. In the cases of buybacks and inactivity, the optimal level of R&D investment is a decreasing function of $x$. 


3.3 Period One

The overall profit function is given by,

\[
\Pi(x, R(x)) = [p_1(x) - c_L]x + \delta[(1 - d(R))\Pi_2^f(x) + d(R)\Pi_2^s(x)] - \delta C(R).
\]

If the firm can make a commitment to a level of R&D before the first-period sales, the firm considers the effect of the R&D activity on the first-period profit. \(R^c\) denotes the firm’s optimal R&D level when it can make a commitment. \(R^c\) is given by,

\[
\frac{\partial p_1(x, R^c)}{\partial R^c} x + \delta d'(R^c)(\Pi_2^s(x) - \Pi_2^f(x)) = \delta C'(R^c) \tag{5}
\]

When the firm cannot make a commitment, the R&D level is determined by equation (4). If we compare equations (4) and (5), the difference is \(\frac{\partial p_1(x, R^c)}{\partial R^c} x\). That is, the firm would internalize the effect of R&D on the first-period price of product L in the commitment case.

**Net sales**

In the case of net sales, the second-period price of product L is not affected by the R&D result. Since \(\frac{\partial p_1(x, R^c)}{\partial R^c}\) is zero, \(R^c\) is the same as \(R^*\). That is, the level of R&D investment is unchanged whether or not the monopolist can commit to the level of R&D investment. Therefore, the monopolist does not face the time-inconsistency problem in the R&D decision, and the firm’s overall profit function is decomposed into two (unrelated) parts.

\[
\Pi(x, R) = A(x) + \delta B(R)
\]

where \(A(x) = (p_1 - c_L)x + \delta \Pi_2^f(x)\) and \(B(R) = d(R)(1 - \theta_H)[(V_H - V_L)\theta_H - (c_H - c_L)] - C(R)\).

\(A(x)\) represents the profit from product L, which is the same as the standard profit function of a durable-goods monopolist with only product L. \(B(R)\) represents the profit from the R&D opportunity. Since \(A(x)\) and
$B(R)$ are independent of each other, the R&D decision is separated from the intertemporal pricing decision.

**buybacks and inactive**

When $x$ is in either the ‘buy back’ or the ‘inactive’ range, $p_L$ falls by a larger amount when the R&D succeeds than when the R&D fails. Thus, the first-period price of product $L$ decreases in the expected R&D investment level. Since $\frac{\partial p_L(x,R^c)}{\partial R} < 0$, we have $R^c < R^*$: Before selling product $L$ in period one, the firm wants to convince consumers of a low level of R&D investment. However, after selling product $L$, the firm wants to invest more for product $H$. That is, the firm faces the time-inconsistency problem in its R&D decision.

**Proposition 1.** When it is optimal for the firm to be a net seller of product $L$ in period two, there is no interaction between the R&D decision and the optimal pricing decision. However, in the cases of buybacks and inactivity, the monopolist faces the time-inconsistency problem in its R&D decision.

There is a dichotomy between different second-period pricing regimes. When the firm is a net seller of product $L$ in period two, there is no time-inconsistency problem. However, when the firm is either inactive or buys back, there exists the time-inconsistency problem as Waldman (1996) predicts.

Example 1. (Net Sales) Suppose that $c_L = 0$, $c_H = \frac{1}{2} - \frac{1}{2}\varepsilon$, $V_L = 1$, and $V_H = \frac{3}{2}$. Without product $H$, in period two the firm will maximize $(1 - \theta_L - x)\theta_L$ by choosing $\theta_L$. Its optimal $\theta_L$ is $\frac{1-x}{2}$, and $p_L$ becomes $\frac{1-x}{2}$. However, if the firm introduces product $H$, the firm will sell additional units of product $L$ in period two for any $x \leq 1 - \varepsilon$. The firm maximizes $(1 - \theta_L - x)\theta_L + (1 - \theta_H)\left[\frac{1}{2}\theta_H - (\frac{1}{2} - \frac{1}{2}\varepsilon)\right]$ by choosing $\theta_L$ and $\theta_H$. $\theta_L^* = \frac{1-x}{2}$, $\theta_H^* = 1 - \frac{1}{2}\varepsilon$, and $p_L$ becomes $\frac{1-x}{2}$. Thus, whether or not the firm introduces product $H$, the first-period price of product $L$ is $(1 - x) + 2\frac{1-x}{2}$. Thus, the time-inconsistency problem does not arise.

Example 2. (Buy-back) Suppose that $c_L = \frac{1}{2}$, $c_H = \varepsilon(V_H - V_L)$, and $V_L = 1$. Without product $H$, the firm will maximizes $(1 - \theta_L - x)(\theta_L - \frac{1}{2})$
by choosing $\theta_L$. Its optimal $\theta_L$ is $\frac{3-2x}{4}$, and $p_L$ becomes $\frac{3-2x}{4}$. However, if the firm introduces product $H$, the firm will buy back product $L$ in period two for any $x > \varepsilon$. The firm maximizes $(1-\theta_L-x)\theta_L + (1-\theta_H)(V_H-V_L)(\theta_H-\varepsilon)$ by choosing $\theta_L$ and $\theta_H$. $\theta_L^* = \frac{1-x}{2}$, and $\theta_H^* = \frac{1+x}{2}$. $p_L$ becomes $\frac{1-x}{2}$, which is lower than $\frac{3-2x}{4}$. When the firm is expected to spend $R$ on the R&D, the first-period price of product $L$ is $(1-x) + \delta[p(R)\frac{1-x}{2} + (1-p(R))\frac{3-2x}{4}]$, which decreases with $R$. Thus, the firm faces the time-inconsistency problem.

4 Discussion

4.1 A Two-Type Model

In Waldman (1996), there are only two discrete types of consumers, high ($\theta_H$) and low ($\theta_L$). The numbers of high and low-type consumers are denoted by $N_H$ and $N_L$, respectively. For a finite number of consumers, we use rational expectation equilibrium as the solution concept. In Waldman’s setup, there are no Coasian dynamics: $\theta_L$ is so low that the firm has no incentive to sell any product to low-type consumers. The following examples will demonstrate that the assumption is essential in deriving the time-inconsistency problem in the R&D decision.

Example (without Coasian Dynamics) Let $V_L = 1, V_H = 3, N_L = 2, N_H = 1, c_H = 2, \theta_L = 1, \theta_H = 5$ and $\delta = 1$. We assume that $c_L$ is higher than $\theta_L V_L$, the maximum amount the low type is willing to pay. Thus, there are no Coasian dynamics. For this example, it is easily shown that the monopolist sells product $L$ to only high-type consumers in period one. Suppose that the firm commits not to introduce product $H$ in period two. Then, the firm is inactive in period two, and $p_L$ is 5. In period one, high-type consumers are willing to pay $\theta_H V_L + \delta p_L = 10$ for product $L$.

Now consider what happens if the firm commits to introduce product $H$. In period two, the firm will sell product $H$ to the high-type consumers, and the high-type consumers will sell their product $L$ to low-type consumers at $\theta_L V_L$, which is 1. In period one, high-type consumers are willing to pay...
\( \theta_H V_L + \delta p_L = 6 \) for product \( L \). Thus, the advent of product \( H \) affects the price path of product \( L \). As Waldman (1996) points out, the firm faces the time-inconsistency problem in its R&D decision.

Let us look at what would happen if the low-type consumers are attractive enough that the firm will optimally sell its product \( L \) to the low-type consumers in period two.

**Example (with Coasian Dynamics)** Suppose that \( c_L \) is lower than \( \theta_L V_L \). If the firm does not introduce product \( H \), the firm will sell product \( L \) to the low-type consumers in period two, and \( p_L \) becomes 1. In period one, high-type consumers are willing to pay \( \theta_H V_L + \delta p_L = 6 \) for product \( L \).

Now consider what happens if the firm commits to introduce product \( H \). After buying product \( H \), the high-type consumers will sell their product \( L \) to low-type consumers at \( \theta_L V_L = 1 \) in period two. So \( p_L \) becomes 1. High-type consumers are willing to pay \( \theta_H V_L + \delta p_L = 6 \) for product \( L \) in period one. Thus, the advent of product \( H \) does not affect the price path of product \( L \).

The example above show that the interactions between the firm’s pricing and R&D decisions are quite different, depending on the existence of Coasian dynamics.

We will generalize the result that, if the Coasian dynamics exist in the two-type model, the second-period price of product \( L \) does not depend on the advent of product \( H \), regardless of the second-period pricing regimes.

Suppose that the firm fails in developing product \( H \). Then, the firm optimally sells product \( L \) to low-type consumers in period two, and the price of product \( L \) becomes \( \theta_L V_L \).

Suppose that the firm succeeds in developing product \( H \) and that the firm optimally sells product \( H \) to only high-type consumers. After buying product \( H \), high-type consumers sell their product \( L \) to low-type consumers in the secondhand market. The firm’s policy on product \( L \) depends on the relative size of \( N_H \) and \( N_L \).

If \( N_H < N_L \), then the firm will optimally sell \( N_L - N_H \) amount of product \( L \) to low-type consumers, and the price of product \( L \) becomes \( \theta_L V_L \).
If $N_H > N_L$, then the firm’s optimal policy on product $L$ is to buy back product $L$. If the firm is inactive in product $L$, $p_L$ becomes zero, and $p_H$ becomes $\theta_H(V_H - V_L)$. The firm’s profit is $(p_H - c_H)N_H$, which is $(\theta_H(V_H - V_L) - c_H)N_H$. However, the firm can increase both $p_L$ and $p_H$ by buying back some amount of product $L$. If the firm buys back $(N_H - N_L)$ amount of product $L$, $p_L$ becomes $\theta_L V_L$, $p_H$ becomes $\theta_H(V_H - V_L) + \theta_L V_L$, and the firm’s profit is $(p_H - c_H)N_H - p_L(N_H - N_L)$, which is $(\theta_H(V_H - V_L) + \theta_L V_L - c_H)N_H - \theta_L V_L(N_H - N_L)$.

The profit level in the buy-back regime is higher than the profit level in the inactive regime by $N_L \theta_L V_L$.

If $N_H = N_L$, then the firm’s optimal policy on product $L$ is also to buy back product $L$ at $\theta_L V_L$. If the firm is inactive in product $L$, $p_L$ will be any number between 0 and $\theta_L V_L$, and $p_H$ becomes $\theta_H(V_H - V_L) + p_L$. If the firm chooses buying back product $L$, $p_L$ becomes $\theta_L V_L$, and the firm’s profit in the buy-back regime is $(\theta_H(V_H - V_L) + \theta_L V_L - c_H)N_H$, which is equal to or higher than the profit level in the inactive regime.

Thus, for all the three cases, $p_L$ is $\theta_L V_L$. Regardless of the second-period pricing regimes, the price of the low-quality product does not depend on the advent of product $H$, and there is no time-inconsistency problem.

Our article investigates the interactions between old and new products with the more generalized demand structure, a continuum of consumer types. Contrary to the two-type model, with the continuous-type model, the firm can choose its optimal cut-off points continuously, and the firm’s optimal $\theta_L$ is different between the net-sales and the buy-back cases. Let us compare the firm’s profit functions under the net-sales and the buy-back regimes (equations (2) and (3)). While it costs $c_L$ for the firm to produce product $L$ under the net-sales case, buying back product $L$ does not incur any production cost. That is, the firm’s (perceived) $c_L$ is zero in the case of buybacks. Since the firm’s perceived $c_L$ is lower in the buy-back case than in the net-sales case, the firm’s optimal $\theta_L$, or, equivalently, $p_L$ is lower in the buy-back case than in the case of net sales. Thus, in the continuous type model, the advent of product $H$ depresses the price of product $L$ more in the case of buy-back than in the case of net-sales.
4.2 Separation Result

In this subsection, we will compare the following two cases: in one case the firm can sell product $L$ and an upgrade (the difference between products $L$ and $H$, $V_H - V_L$). In the other case, the firm can sell products $H$ and $L$. We will find some conditions under which these two cases are equivalent in terms of the firm’s profit maximization.

Case A: Suppose that the firm, by physically dividing product $H$ into product $L$ and the upgrade, can sell the upgrade separately. A consumer can get high-quality product by combining product $L$ and the upgrade. Case A may not be realistic for some goods. (How can we divide a new digital camera into an old model and an upgrading part?) However, this case can be a good benchmark. In this case, the firm maximizes its profit by choosing $\theta_L$ and $\theta_U$, where $[\theta_L, 1]$ consumers use product $L$, and $[\theta_U, 1]$ consumers buy the additional upgrade. The profit function is as follows,

$$\Pi_2 = (1 - \theta_L)(V_L\theta_L - c_L) + (1 - \theta_U)[(V_H - V_L)\theta_U - (c_H - c_L)],$$

where $(V_H - V_L)$ and $(c_H - c_L)$ can be interpreted as the upgrade and as the unit production cost of the upgrade, respectively.

In case A, the firm faces two markets: one is product $L$, and the other is the upgrade. The firm in case A can provide the upgrade without lowering the price of product $L$.

Case B: Since the improved functions are embodied into product $H$, the firm cannot sell the upgrade separately. If a consumer wants high-quality features, she must buy product $H$. Since product $H$ has all the features of product $L$, when the firm provides product $H$, it has a negative effect on the price of product $L$.

Let us compare case A with case B. The control variables for the firm in case A are the number of product $L$ and that of the upgrade. The control variables for the firm in case B are the number of product $L$ and that of product $H$. In terms of control variables, choosing the numbers of product $L$
and product $H$ is equivalent to choosing the numbers of product $L$ and the upgrade as long as the intended number of the upgrade is fewer than that of product $L$.

**Example: Net sales case**

Suppose that it is optimal for the firm to sell five units of product $L$ ($5c_L$) and three units of the upgrade ($3(c_H - c_L)$). Even if the firm cannot separate the upgrade from the new product, the firm can achieve this optimal outcome by selling two units of product $L$ ($2c_L$) and three units of product $H$ ($3c_H$). Note that both cases incur the same costs and the same quantities. The firm in Case A provides a smaller number of units of the upgrade than that of product $L$, which is the case of net sales. Thus, in the case of net sales, the market outcomes are the same as if the firm could separate the upgrade from product $H$.

**Example: Zero production cost**

Suppose that the intended number of the upgrade is larger than that of product $L$. For instance, suppose that the firm wants to provide five units of the upgrade ($5(c_H - c_L)$) in case A. The firm in case B can achieve the same outcome by producing five units of product $H$ ($5c_H$) and buying back five units of product $L$. However, the firm in case B has an extra production cost ($5c_L$). Thus, cases A and B are different. However, one special case is that the unit production cost is zero. When $c_L$ is zero, we can ignore the extra production cost. Thus, by selling product $H$ and buying back product $L$, the firm can provide the improved functions without changing the price of product $L$. Thus, Cases A and B are equivalent: we get the separation result when the unit production cost of product $L$ is zero.

## 5 Conclusion

Since consumers are aware of the possibility that a new product will be introduced in near future, they are reluctant to pay a high price for a current good and may choose to wait for the new product. The firm must consider the interaction between its intertemporal pricing and R&D decisions. The
interactions depend on the pricing regimes. If it is optimal for the firm to
discontinue the sale of the current product after introducing the new product,
the firm faces the time-inconsistency problem in its R&D decision. However,
if it is optimal for the firm to continue to sell the current product along with
the new product, the interactions disappear.

There are several directions in which the analysis of this paper could be
extended. In the analysis above, all consumers can buy product $H$ for the
same price whether or not they have already bought product $L$. However,
a firm may be able to identify its former patrons and price discriminate
consumers based on the information. It would be interesting to investigate
the interaction between intertemporal pricing and the R&D decision in such
a situation.
References


Notes

1. In the case of non-durable goods, a current product on the market will be consumed away by the time a firm introduces a new product. Thus, there is no direct linkage between a current product and a new product.

2. A durable-goods monopolist faces a time-inconsistency problem known as Coasian dynamics in its pricing decision. After making sales in period one, the monopolist sells its product to the residual demand in period two by lowering its price. However, rational consumers, anticipating the price drop, will wait for the price to drop. As a result, the durable-goods monopolist is forced to charge a low price in period one. Since Coase (1972) examined this issue, several studies have investigated durable-goods pricing. See Stokey (1981), Bulow (1982), Bond and Samuelson (1984), Conlisk, Gerstner and Sobel (1984), Gul et al. (1986), Ausubel and Deneckere (1989), Bagnoli et al (1989) and Dudey (1995).

3. The marginal type of a product is the lowest type among consumers who buy the product. Since the marginal type determines the price of a product, the firm can be regarded as maximizing its profit by choosing its marginal type.

4. The number of units shipped of the 80286 peaked at 1989.

5. Lee and Lee (1998) analyze the monopolist’s R&D decision, but they assume that the firm sets the R&D plan before the first-period sales. Therefore, the technological innovation is exogenous when the firm makes the first-period sales.

6. If the market consists of an atomless continuum of buyers, each buyer’s current purchase does not affect future prices. However, if the market demand consists of a finite number of consumers, buyers consider the effect of their current purchases on future prices. For details, see Bagnoli et al. (1989) and Dudey (1995).

7. The main results of this paper do not depend on the uniform distribution. As long as consumers’ types are continuously distributed, we get the same results.

8. A consumer of type $\theta$ is willing to pay $\theta$ for renting product $L$ for one period. When the rental price is $r$, the demand for renting product $L$ for period one is $1 - r$. Therefore, when the firm sells $x$ units of product $L$ in period one, the rental price of product $L$ in period one becomes $1 - x$.

9. When $x$ is between $\frac{c_H - c_L}{V_H - V_L}$ and $\frac{c_H}{V_L}$, the firm chooses to be inactive. Thus, $\frac{1 - x + c_L}{x} > p_L^{\text{inactive}}(x)$.

10. Consumers make their first-period consumption based on their expectation of the
second-period price. In an rational expectation equilibrium, the second-period price
is equal to the consumers’ expected second-period price. For the difference between
rational expectation equilibrium and SPNE, see Dudey (1995).

11The actual amount of product $L$ the firm buys back is zero.

12Depending on parameter values, we can have different outcomes. For instance,
the firm may optimally sell product $H$ to both high and low types. Then, the price of
product $L$ becomes zero, which is lower than $\theta_L V_L$. We have the time inconsistency
problem in this case.