DURABLE GOODS AND PRODUCT OBSOLESCENCE

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The issue of product obsolescence is addressed by examining the optimal sales strategy of a monopolist firm that may introduce an improved version of its current product. Consumers' expectations of a forthcoming product lowers the price that they are willing to pay for the current product because of its loss in value due to obsolescence. The new product is characterized by consumers' increased willingness to pay and by its competitive interaction with the old product. These characteristics affect the tradeoff that the firm makes between the cost of waiting for new product sales versus the cost of cannibalizing these sales. We analyze the effect of these characteristics of the new product on the firm's optimal sales strategy. We consider the various policy measures available to the firm, including limiting initial sales in order to lower cannibalization of the new product, buying back the earlier version of the product in order to generate greater demand for the new product, and announcements of future product introductions. We find that, for modest levels of product improvement, the firm's optimal policy is to phase out sales of the old product, while for large improvements a buy-back policy is more profitable. Lastly we find that the firm is better off if it informs consumers whether a new product is forthcoming.

(Durable Goods; Product Obsolescence; Buy-Backs; Cannibalization)

1. Introduction

In purchasing durable goods, consumers must not only evaluate the product in terms of its price and quality, but also consider the good's future value as well. Researchers have begun to consider the impact of possible future price decreases both on consumers' behavior and, in turn, on the optimal sales strategy of firms (Stokey 1981; Bulow 1982). An important means by which the value of a durable good may change is if a new, superior product is introduced which makes the old product obsolete. Obsolescence is defined as the relative loss in value due to styling changes (style obsolescence) or quality improvements (functional obsolescence) in subsequent versions of the product. In markets where technological improvements and styling changes are frequent, product obsolescence is an important phenomenon because consumers are reluctant to invest in a product that can soon be superseded. In addition to these effects of predictable or systematic changes, uncertainty over future improvements may cause consumers to delay their purchase of the good or reduce their valuation of it (Rosenberg 1976). For example, rumors that IBM was introducing a new product that would make the PC and the PC/XT obsolete lowered their current sales (Business Week 1986).

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This paper analyzes the strategy of a monopolist firm that sells a durable product for which it may subsequently introduce an improved version, where the strategy reflects the effect of consumers’ expectations of future prices and the obsolescence of the old product.

Pricing durable products poses particular problems for marketing strategists. The market for new durable goods tends to become saturated since the products are long lived. Furthermore, the durability of the product suggests that second hand markets may play an important role. In particular, the second hand market may constrain the firm’s pricing policy by serving as an alternative source of supply (Swan 1980). Finally, because of their long life and the possibility of second hand markets, durable products can be considered as capital investments by consumers. As with valuing any capital asset, consumers must assess the asset’s future value as well as its immediate returns. With durable products, the future value is affected by future price decreases and the possible introduction of a new version of the product that may, in part, make the earlier version obsolete.

Research in marketing on the pricing of durable goods has focused principally on the first characteristic, market saturation, and has considered the pricing trajectory over time. Starting with Bass’s (1969) work on the role of diffusion of demand, research on the monopolistic pricing of new products have included explicitly incorporating price in the Bass model (Robinson and Lakhani 1975) and determining the optimal time path of pricing, given diffusion effects on demand and experience curve effects on production costs (Bass 1980; Dolan and Jeuland 1981; Jeuland and Dolan 1982; Kalish 1983). The focus of this research has been on the implications of declining marginal costs and diffusion of demand for pricing durable products. More recently, the role of durable goods as an entry barrier and their effect on the dynamics of duopolistic and oligopolistic price competition have been explored (Clarke and Dolan 1984; Rao and Bass 1985; Eliashberg and Jeuland 1986). Both these streams of research have focused on the pricing dynamics of a product that is itself stable over time. Consumers’ expectations about the firm’s future pricing policies or new product introductions are not incorporated in these models. However, in practice, expectations of future price decreases or new product introductions may affect current demand.

Within the economics literature, there is a stream of research, inspired by a paper by Coase (1972), on the price trajectory of durable goods. Coase made the following intuitive argument. Consider a monopolist firm that sells the static monopoly quantity of a durable good. Having sold this quantity, the firm still faces a residual demand curve for the good, consisting of those consumers who place a value on the good lower than the current price. The monopolist then has an incentive to reduce the price of the good and make additional sales to this residual group of consumers. This process should continue until the price reduces to the marginal cost of production. Consumers, anticipating this reduction in price, would therefore postpone their purchase. Thus, Coase conjectured that the market price should fall to the competitive level in the “twinkling of an eye.” Stokey (1981) formalizes Coase’s conjecture and proves that as the time periods between the monopolist’s production decisions becomes arbitrarily small, the market price approaches marginal cost. Subsequent researchers have enriched the analysis and derived settings in which the Coase conjecture does not hold due to depreciation of the durable good (Bond and Samuelson 1984), increasing costs of production (Kahn 1986), and changes in the quality of the good (Kumar 1987).

There has been some prior research on technological obsolescence from the perspective of both consumers and firms. Researchers focusing on the consumers’ problem have modeled the demand for a new product or innovation as a one-time decision to adopt (e.g., Balcer and Lippman 1984; McCardle 1985; Weiss 1987). Consumers decide whether to adopt the current state-of-the-art product or wait until a future period
when the product will be improved even further. They can "leapfrog" by choosing not
to adopt the current generation of the product in favor of the forthcoming generation. If
consumers are uncertain as to the profitability of the new product, then it may be
worthwhile to delay adoption and acquire more information in order to update their
beliefs (Jensen 1982; McCardle 1985; Weiss 1987). This literature consists of decision
theoretic models of consumer behavior that treat the price of the new product as
exogenous and ignore the possible role of second hand markets. An important contri-
bution of this paper is to develop an equilibrium model of a profit maximizing firm and
strategic consumers, who anticipate the implications of the firm's sales policy for future
prices.

Within the context of work that characterizes the firm's optimal sales strategy, obso-
lescence has been modeled by using the durability of the product as a proxy (Swan
1972; Schmalensee 1979; Bulow 1986). However, durability is not a satisfactory proxy
for obsolescence. The decrease in value that results from product obsolescence is not
due to the good becoming less useful or productive, but by its being superseded by a
superior product. The extent of this obsolescence is related to the size of the improve-
ment in the new version and the degree to which the old and the new products compete
for the same segment of the market.

We explore the effect that consumers' expectations of new product introductions
have on the optimal strategy of a firm which may introduce an improved version of its
product at a later date. In addition, we incorporate the role of the second hand market
for used durables and the effects of anticipated obsolescence on the demand for the
current generation of the product. We consider the various policy measures available to
the firm, including limiting initial sales in order to lower cannibalization of the new
product, buying back the earlier version of the product in order to generate greater
demand for the new product, and announcements of future product introductions.

We develop a two-period model of a monopolist firm that sells the old product in the
first-period and is able to introduce a new product in the second-period. The new
product is characterized by the average increase in consumers' willingness to pay and
the degree to which the old product competes with the new product. The degree to
which sales of one product reduce the potential sales of the other is determined by the
competitive interaction between the products. If the demand for the new product is
based entirely on new consumers entering the market or from another segment of the
market, then there is no competitive interaction between the old and the new versions
of the product. Alternatively, if the level of interaction is high, then sales of the old
product in period 1 cannibalize sales of the new product in period 2.

New product introductions are studied under two basic assumptions. In one case, it is
assumed that the firm can precommit to phasing out the old version of the product
subsequent to the introduction of the new one. We refer to this setting in which the firm
commits itself to sell the old product in period 1 and only the new in period 2 as
separate production. As the improvement of the new over the old increases, the optimal
level of sales of the old product in period 1 decreases and declines to zero for sufficiently
large improvements. Thus, the prospect of a superior product in the future can lead the
firm to stop selling the current product, even though consumers value the service
provided by the current generation of the product. ¹

In the other case, the firm determines its optimal product policy sequentially. There-
fore, in period 2 the firm decides whether to concurrently sell the old and new products

¹ This result is analogous to the phenomenon of leapfrogging behavior on the part of consumers. In contrast
to the case of leapfrogging where consumers do not adopt the current technology, in this context the firm
chooses not to sell the old version of the product. The firm's motivation for this is to eliminate the cannibali-
zation of new product sales.
(joint production) or to sell the new product and buy back some of the old product. The advantage of buying back some of the old version is that it reduces cannibalization of new product sales. When the magnitude of the improvement of the new product is small, the firm finds it optimal to sell both the old and the new products in the second period. However, as the magnitude of improvement increases so does the cost of cannibalization, and the firm chooses to buy back some of the old product. We show that profits under a separate production strategy are unambiguously higher than joint production profits, suggesting that the firm does better if it can commit itself to phasing out the older generation of the product. A buy-back strategy results in higher profits than separate production when the magnitude of the improvement in the new product is large. A large improvement in the new product has two effects. It increases the cost of cannibalizing new product sales and makes the old product more obsolete which, in turn, drives down the buy-back price of the old version. Both these effects cause the buy-back policy to become more desirable.

We explore the firm's optimal sales strategy of new product introductions first under the assumption that the introduction is certain and, subsequently, under the assumption that consumers have only some probabilistic beliefs about the possible introduction of a new product. In the case where new product introduction is uncertain, we consider whether it is in the firm's interest to signal to consumers whether or not a new product is forthcoming. If the firm does not communicate any information, then consumers incorporate their beliefs about the likelihood of a new product being introduced into their demand for the product in period 1. We show that, for a risk neutral firm, profits are higher if the firm signals to consumers whether a new product is forthcoming.

The remainder of this paper is organized into four sections. The basic model of a durable goods monopolist is laid out briefly in §2. §3 introduces the new product model under the cases of separate production and joint production with a buy-back policy. In §4, we compare the sorting and pooling equilibria. Finally, §5 summarizes the results and presents some ideas for future research.

2. Basic Model

In this section, we present the model developed in Bulow (1982) of a durable goods monopolist. Consumer demand is represented by a linear demand curve. This assumption of a downward sloping demand curve allows for saturation effects and implies that the price of the product declines with cumulative production. We assume that the product does not deteriorate and can be sold in a second hand market in period 2. The existence of the second hand market serves two roles. First, it constrains the ability of the firm to price discriminate because of the "competition" from the resale market. Second, even though the demand curve is modeled as static, the second hand market permits different individuals to do the demanding each period. In particular, if the demanders in one period have no use for the product in the following period, they can sell it in the resale market. The model assumes that the firm has constant marginal costs. Without loss of generality, these are set to zero. Cost dynamics through experience curve effects are precluded through this assumption of constant costs. Previous researchers have explored the implications of experience curve effects on the pricing strategy of firms. Our focus is on the pricing implications of product obsolescence, not the role of cost reductions through experience curve effects.

2 Deterioration of the product can be accounted for in this model by allowing only some proportion of the product sold in period 1 to be available on the second hand market in period 2, or by lowering the value of the good to consumers by some constant amount.

3 A positive product cost is equivalent to shifting the demand curve inward.
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An important assumption of the analysis is that the price consumers are willing to pay for a durable good reflects not only the value to them of the product, but also their expectations about the price of this product in the future. Expectations of how future prices may change are reflected by two factors. The first is the extent to which new products will improve upon the existing product. Consumers’ expectations of the extent to which the price of the existing product will decline over time increases with the improvement represented by the new product. For instance, if consumers know that a major product improvement is forthcoming for video cameras, they are likely to believe that the price of the existing line of cameras will fall substantially in the future. The second consideration is simply the level of current sales. Since durable goods are subject to saturation effects, a large level of current sales reduces the market for the good in the future. This tends to drive down the price in future periods. Rather than postulate some arbitrary process of expectation formation, we assume that consumers’ expectations are rational in the sense that they are able to forecast second-period price based on their observation of first-period sales and their knowledge of future product improvements. However, even if consumers are myopic and believe that the price in later periods is independent of current sales and future product improvements, the firm must still trade-off first-period sales with protecting the market for new products. Thus, the qualitative nature of our results are quite robust to the nature of consumer expectations.

Demand for the services yielded by the good is given by

$$r = \alpha - \beta q$$

(1)

where $r$ is the one period rental price, $q$ is the cumulative quantity produced to date, and $\alpha$ and $\beta$ are arbitrary positive constants. Suppose the firm sells a quantity $q_1$ in period 1. Consumers then form expectations about the price of the product in period 2 based on sales of $q_1$ and the resulting price. Given that the firm has sold a quantity $q_1$ in period 1, the effective demand curve in period 2 is $\alpha - \beta (q_1 + q_2)$, where $q_2$ is the quantity sold in period 2. In order to maximize revenues in period 2, the firm chooses a quantity $q_2$ to equate its marginal revenues and marginal costs. This revenue maximizing value of $q_2$ is given by $[\alpha / (\beta - q_1)] / 2$. The price that consumers are willing to pay for the product in period 1 is a sum of the rental price in period 1 and the discounted rental price in period 2, with $\rho$ representing the discount rate:

$$p_1 = (\alpha - \beta q_1) + \frac{\alpha - \beta q_1}{2(1 + \rho)}.$$  

(2)

The problem of the monopolist is to maximize profits and is stated as

$$\text{Max } \Pi_{q_1, q_2} = q_1 \left[ (\alpha - \beta q_1) + \frac{\alpha - \beta q_1}{2(1 + \rho)} \right] + q_2 \frac{\alpha - \beta q_1}{2(1 + \rho)}.$$  

(3)

The optimal quantities given by the solution to this maximization problem are

$$q_1^* = \frac{2\alpha(1 + \rho)}{\beta(5 + 4\rho)},$$  

$$q_2^* = \frac{\alpha(3 + 2\rho)}{2\beta(5 + 4\rho)}.$$  

(4)

As the discount rate approaches infinity, the optimal quantities approach the standard, myopic monopolist solution. However, even in this case, the optimal second-pe-

\* A $\rho$ value of 0 corresponds to no discounting of the future, while an infinite discount rate corresponds to a myopic decision maker.
 period sales are diminished by the availability of period 1 output on the resale market. More generally, the monopolist reduces sales in the first-period in order to sustain a higher price for the product in the second-period. It is this tradeoff between extracting profits early on and preserving a profitable market in the future that is the essence of Bulow's analysis.

3. New Product Model

In this section, we extend the two-period model outlined above by assuming that the monopolist is able to introduce a new version of the product in period 2. We assume that demand for the new product is characterized by a linear demand curve. The new product is represented by the degree to which it is more highly valued and its competitive interaction with the old product. The greater the extent to which the old and new products draw sales from the same segment of the market, the greater the competitive interaction between the products. A higher degree of competitive interaction results in a greater cannibalization of sales.

Figure 1 shows the demand curves for the old and the new products. The demand curve for the new product, $D_N$, is represented as a parallel shift to the right from $D_o$, the demand for the old product. One can view this shift as resulting from new consumers entering the market, or, as an increase in current consumers' valuation of the product. The magnitude of this shift is represented by $\delta$. The cost of the new product may exceed that of the old and, in this case, $\delta$ represents the change in the firm's margin (price - marginal cost) for a given level of sales.

The second characteristic of the new product is the manner in which it competes with the old product. For example, consider the introduction of stereo television sets. Some of the purchasers of stereo sets are first time buyers of televisions, while many others...
already own a conventional set. If purchases of stereo televisions are made by individuals who would not otherwise buy a conventional set, then the new stereo set does not compete with conventional sets. More generally, if the new product is in a different segment of the market, then the new product does not compete with the old one. In the case of television sets, the products may be noncompeting for a number of individuals, but not for the market as a whole. We use the parameter $\gamma$, where $0 \leq \gamma \leq 1$, to represent the degree to which the old and new products compete with one another. A $\gamma$ value of 0 implies that there is no competition between the two products, while a value of 1 implies that a sale of one product diminishes potential sales of the other by one unit. There would appear to be an asymmetry in the manner in which old and new products compete with each other. For example, a prior purchase of a conventional television set may not eliminate one from the market for a new stereo television. In contrast, it is more likely that the prior purchase of a stereo television set will remove one from the market for a conventional set. Rather than introduce a separate parameter for how the old product competes with the new and how the new product competes with the old, we assume that each unit sold of the new product diminishes the demand for the old version by one unit and that demand for the new product is diminished by $\gamma$ for each unit of the old product sold. The analysis is not sensitive to this restriction. What is important, is that we rule out the unlikely case of the old version more readily substituting for the new version than the new version does for the old.

In general, one would expect there to be some relationship between the increase in valuation of the new product over the old, $\delta$, and the degree to which the old product competes with the new. For instance, a smaller increase in consumers’ willingness to pay might imply that consumers perceive the old product to be a strong substitute for the new, which would lead to a higher $\gamma$. For the sake of clarity, we assume that the two effects are independent.5

3.1. Separate Production

In this setting, the firm sells the old product in period 1 and only the new product in period 2. This may result from the high cost of running two production lines, as is the case in automobile manufacturing. Alternatively, the firm may have publicly committed itself to such a new product introduction strategy. The rental prices are given by

$$r_{1,i} = \alpha - \beta q_{1,i},$$

$$r_{2,i} = \alpha - \beta (q_{1,i} + q_{2,i}),$$

$$r_{2,i,n} = (\alpha + \delta) - \beta (\gamma q_{1,i} + q_{2,i}),$$

where $r_{i,j}$ is the one-period rental price of the $j$th product in the $i$th period and $q_{i,j}$ is the quantity of the $j$th product in the $i$th period. Since the old and new products are comparable, sales of one decrease the price of the other. Thus, in period 2 the rental price of the old product is influenced by the sales of the new product, as well as the period 1 sales of the old product available on the second hand market. Similarly, period 1 sales of the old product reduce the price of the new product in period 2. Since the old product is not a perfect substitute for the new, prior sales of the old product have a less than one-for-one effect on the demand for the new product. The potential sales of the new product that are cannibalized are represented by $\gamma q_{1,i}$ and are referred to as unit cannibalization. If the products do not compete with one another, then unit cannibalization is zero. Alternatively, if the products are competing for the same market segment, then unit cannibalization would be $q_{1,i}$.

5 This assumption is only necessary for the examination of the comparative statics of the model. The characterization of the equilibrium quantities and the comparison of the sorting and pooling equilibria in §4 do not depend on this assumption.
Suppose that in period 1 the monopolist sells a quantity $q_{1,o}$ of its product. Upon observing the resulting price, consumers form expectations about the price decrease of the old product in period 2. If a new product is developed, then the future price decrease results from obsolescence of the old product, as well as from market saturation through sales of the new version. The price that consumers are willing to pay for the product in period 1 incorporates their expectations of future price decreases of the old product. Thus, the problem of the firm, given that it has sold a quantity $q_{1,o}$, is to market a quantity $q_{2,n}$ that equates marginal revenues and marginal costs, yielding

$$q_{2,n} = \frac{(\alpha + \delta) - \beta \gamma q_{1,o}}{2}.$$  

(1)

Substituting for $q_{2,n}$ in expressions (7) and (8), we get the rental prices of the old and the new products in period 2:

$$r_{2,o} = \frac{(\alpha - \beta q_{1,o}) - (\delta + \beta q_{1,o}(1 - \gamma))}{2},$$  

(9)

$$r_{2,n} = \frac{(\alpha + \delta) - \beta \gamma q_{1,o}}{2}.$$  

(10)

Note that the rental price of the old product in period 2, $r_{2,o}$, reflects the decrease in value of the old product due to obsolescence. The first part of the expression for $r_{2,o}$ is the price of the old product had a new version not been developed. The second part represents the loss in value due to obsolescence. The extent of the loss in value due to obsolescence increases with $\delta$ and is lessened by $\gamma$, the degree to which the old product competes with the new version. Since period 2 is the last period, the rental price of the new product is also its selling price. In contrast, the selling price of the old product in period 1 is the sum of the period 1 rental price and the discounted period 2 rental price.

$$p_{1,o} = (\alpha - \beta q_{1,o}) + \frac{(\alpha - \delta) - \beta q_{1,o}(2 - \gamma)}{2(1 + \rho)}.$$  

(11)

The problem of the monopolist is to maximize profits over these two periods.

$$\text{Max} \Pi_{q_{1,o}q_{2,n}} = q_{1,o}\left[ (\alpha - \beta q_{1,o}) + \frac{(\alpha - \delta) - \beta q_{1,o}(2 - \gamma)}{2(1 + \rho)} \right] + q_{2,n}\frac{(\alpha + \delta) - \beta \gamma q_{1,o}}{2(1 + \rho)}.$$  

(12)

The optimal quantities that result from this maximization are

$$q_{1,o}^* = \frac{2\alpha + (\alpha + \delta) - \gamma(\alpha + \delta)}{\beta(8 + 4\rho - 2\gamma - \gamma^2)},$$  

(13)

$$q_{2,n}^* = \frac{\alpha[8 + 4\rho - 5\gamma - 2\gamma \rho] + \delta[8 + 4\rho - \gamma]}{2\beta(8 + 4\rho - 2\gamma - \gamma^2)}.$$  

(14)

If $\delta = 0$ and $\gamma = 1$, that is, there is no increase in valuation and the products compete directly with one another, then the old and new products are identical and expressions (13) and (14) are the same as the quantities in the basic model. In the absence of these extreme values, equations (13) and (14) are rather complex. In order to gain more insight into the firm’s optimal policy, we explore how it is influenced by the various structural parameters of the model.

Of particular interest is how the firm’s policy varies with the nature of the new product. As the amount of improvement represented by the new product, $\delta$, increases, we find that sales of the old product decrease, $\frac{\partial q_{1,o}^*}{\partial \delta} < 0$. For a sufficiently large $\delta$ value, $q_{1,o}^*$ becomes zero and the firm foregoes selling the old product. More precisely, if
the improvement is greater than \( \alpha (3 + 2\rho - \gamma)/(1 + \gamma) \) then the old product is not sold. The firm foregoes selling the old product if the cost of cannibalization of the new product’s sales is greater than the gain in additional profits in the first period. While unit cannibalization, \( \gamma q_{t,o} \), depends on sales of the old product and its competitive interaction with the new version, the cost of cannibalization is the loss in revenues through losing \( \gamma q_{t,o} \) unit sales. This cost depends on \( \delta \), which determines how much greater the firm’s profit margin is for the new product. To reduce the cannibalization cost associated with a higher \( \delta \), the firm reduces its period 1 sales.

The effect of \( \gamma \) on sales in period 1 is less straightforward, but, again, we can understand its influence by focusing on the tradeoff between the cost of waiting for period 2 revenues versus the cost of cannibalizing sales of the new product. Clearly the cost associated with the old product being a stronger competitor for the new (i.e., higher \( \gamma \)) depends upon the relative valuation of the old product and the new. Formally, we can view this as the relative value of the intercepts of the two demand curves: \( \alpha \) and \( \alpha + \delta \). In particular, we have the following result.

**Proposition 1.** \( \partial q_{t,o}^*/\partial \gamma > 0 \) if and only if \( \delta < \delta' \), where

\[
\delta' = \frac{\alpha [2\gamma (3 + 2\rho) - 2 - \gamma^2]}{(10 + 2\gamma + \gamma^2 + 4\rho)} .
\]

Although profits decrease unambiguously with \( \gamma \), the effect of a change in \( \gamma \) on \( q_{t,o}^* \) depends upon the level of the other parameters. Consider a setting in which the firm is in equilibrium and is optimally trading off the cost of waiting and the cost of cannibalization. Suppose that the degree of competitive interaction, \( \gamma \), increases. A higher level of \( \gamma \) has two opposing effects. On the one hand, an increase in \( \gamma \) makes sales of the old product more valuable by increasing its selling price, \( \partial p_{t,o} / \partial \gamma > 0 \) for a given \( q_{t,o}^* \) (see equation (9)). On the other hand, a higher value of \( \gamma \) increases unit cannibalization of new product sales, since sales of the old version now result in larger numbers of consumers being out of the market for the new product. The optimal tradeoff between these two effects depends on the cost of cannibalization and, in turn, on \( \delta \). First consider the case where \( \delta \) is small. A small \( \delta \) means that the cost of cannibalization of new product sales is low. Thus, the firm benefits more by exploiting the increase in consumers valuation of the old product that results from an increase in \( \gamma (\partial p_{t,o} / \partial \gamma > 0) \). Therefore, with a small \( \delta \), \( \partial q_{t,o}^*/\partial \gamma > 0 \). Alternatively, if \( \delta \) is large, then the costs of cannibalization are higher. Now, an increase in \( \gamma \) increases the cost of cannibalization of the new product more than it increases the revenues that the firm can get from the old product. Therefore, with a large \( \delta \), \( \partial q_{t,o}^*/\partial \gamma < 0 \).

As can be seen in equation (15), the cutoff value of \( \delta \) is a function of the discount rate and the degree to which the two versions compete with one another. In particular, \( \partial \delta' / \partial \gamma > 0 \). That is, if the level of competitive interaction is high (low), it requires a larger (smaller) \( \delta \) for \( \partial q_{t,o}^*/\partial \gamma < 0 \). This results from the fact that the value of the old product increases with \( \gamma \). An increase in the discount rate places more weight on the value of period 1 profits and less weight on the cost of cannibalization of new product sales. As a result, an increase in \( p \) raises the cutoff value \( \delta' \).

### 3.2. Joint Production and Buy-Backs

In this section, we explore the firm’s strategy when it determines its optimal sales strategy sequentially. In particular, the firm is not able to precommit to phasing out sales of the old product. In addition, we assume that the firm can buy back some of its period 1 sales of the old product.\(^6\) Thus, in period 2, the firm either concurrently sells

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\(^6\) We are grateful to an anonymous reviewer for the suggestion of using a buy-back strategy in our analysis.
the old and new products or it sells the new product and buys back some of the old product.\footnote{We can also consider a strategy of buy-backs under separate production. However, for small $\delta$’s the firm does not buy-back any of its earlier sales, and this is equivalent to the separate production strategy developed previously. When the firm does buy-back some of its earlier sales, then a separate production/buy-back strategy is equivalent to the joint production/buy-back strategy developed in this section. Therefore, the policy of buy-backs under separate production does not need to be addressed separately.} We refer to the setting in which the firm concurrently produces the old and new versions as \textit{joint production}. A buy-back policy is implemented only when the firm does \textit{not} sell the old version in period 2. We find that when the firm engages in joint production, concurrently selling the old and new products, it earns less profits than if it had precommitted to phasing out sales of the old product in period 2. A buy-back strategy is profitable only when the improvement of the new product over the old is large.

Buy-backs allow the firm to decrease the degree of cannibalization and enhance sales of the new version without foregoing revenues in period 1. An important property of a buy-back policy is that the firm removes the buy-backs from the market so that they do not compete with new product sales. For example, in marketing a new generation of computer software, some manufacturers require consumers to return the copy-protected diskettes of the old version. It is to highlight this property of removing the old version from the market that we use the term buy-backs, rather than the more familiar one of trade-ins. A buy-back policy would also be effective if the firm could resell the buy-backs in a different market segment. For example, U.S. manufacturers often resell used capital equipment in less developed countries. In this case, the used equipment does not negatively influence the demand for the new product. Incorporating this possibility in the model would make buying back the old product even more profitable, since the cost of the buy-back would be reduced.

In practice, firms often have a policy whereby consumers can trade-in their old product for a new version or a higher item in the firm’s product line. Typically, the value of the trade-in is determined by the firm and is often defined as a percentage discount off the new product. In our analysis, we assume that the firm buys back some of its period 1 sales of the old product in the second hand market. This precludes any possibility of arbitraging on the part of the firm by exploiting any difference between the buy-back price and the price in the second hand market. In some sense, a buy-back policy is different from a trade-in in that a trade-in is available only to those consumers who turn in the old product to move up to a new one. However, given our focus on the aggregate market demand and the presence of a second hand market, this distinction is not relevant. We consider the effects of implementing a buy-back policy on the firm’s sales strategy and its profitability.

Suppose that the firm sells $q_{1,o}$ of the old product in period 1. Given this quantity, it must decide in period 2 on the level of sales of the new product and whether to engage in joint production or buy-backs of the old product. Let $q_b$ represent the level of buy-backs or additional sales of the old product in period 2. That is, a positive value of $q_b$ is interpreted as buy-backs of the old product in period 2, and negative values as additional sales of the old product in period 2. Thus, the prices of the old and new products in period 2 are

\begin{align}
    p_b &= \alpha - \beta (q_{1,o} - q_b + q_{2,n}), \\
    p_{2,n} &= (\alpha + \delta) - \beta q_{2,n} - \gamma \beta (q_{1,o} - q_b),
\end{align}

where $p_b$ is the buy-back price if $q_b > 0$ and the selling price in period 2 if $q_b < 0$. By characterizing the optimal second-period decision as a function of the first-period sales, we can state the firm’s optimization problem (see Appendix for details). This is now a
constrained optimization problem in order to ensure that the firm does not buy-back more of the old product than it sold in period 1:

$$\text{Max } \Pi_{q_1, q_b, q_n} = p_{1, o} q_{1, o} - \frac{p_b q_b}{(1 + \rho)} + \frac{p_{2, n} q_{2, n}}{(1 + \rho)}$$

subject to $q_b \leq q_{1, o}$.

The optimal level of period 1 sales is given by

$$q_{1, o}^* = \frac{\alpha (3 + \gamma) (1 + \rho)}{2 \beta \gamma (1 + \rho) + 2 \beta (4 + 3 \rho)}.$$

If the constraint is not binding, the optimal level of buy-backs of the old product and sales of the new product are

$$q_b^* = \frac{\delta (1 + \gamma) - \alpha (1 - \gamma) + \beta q_{1, o}^* (2 - \gamma - \gamma^2)}{\beta [4 - (1 + \gamma)^2]},$$

$$q_{2, n}^* = \frac{\alpha (1 - \gamma) + 2 \delta + \beta q_{1, o}^* (1 - \gamma)}{\beta [4 - (1 + \gamma)^2]}.$$

Whether the firm buys-back some of its earlier sales or concurrently sells both products depends on the value of $\delta$. In particular, when $\delta < \delta_b$ then $q_b < 0$ and the firm sells additional units of the old product in period 2, where

$$\delta_b = \frac{\alpha (1 - \gamma) - \alpha (3 + \gamma) (2 - \gamma - \gamma^2) (1 + \rho)}{(1 + \gamma) [2 \gamma (1 + \rho) + 8 + 6 \rho]}.$$

On the other hand, if $\delta > \delta_b$ then $q_b^* > 0$ and the firm buys back a positive amount of period 1 sales of the old product. Buy-backs increase with $\delta$, $\delta q_b^* / \delta \delta > 0$. Indeed, the firm buys back all its period 1 production when $\delta = \delta_q$, where

$$\delta_q = \frac{\alpha (1 - \gamma) + \alpha (3 + \gamma) (1 - \gamma) (1 + \rho)}{(1 + \gamma) [2 \gamma (1 + \rho) + 8 + 6 \rho]}.$$

Therefore, if $\delta > \delta_q$ then the constraint that $q_b \leq q_{1, o}$ is binding and the firm buys back all its period 1 sales of the old product. When the firm buys back all its prior sales of the old product, then the demand for the new product depends only on sales of the new product (see equation (17)). In this case, the firm sells the new product to the point where its marginal revenues equal costs, $(\alpha + \delta) / 2 \beta$. Therefore, when $\delta \geq \delta_q$ then $q_b^* = q_{1, o}^*$ and $q_{2, n}^* = (\alpha + \delta) / 2 \beta$. If $\delta < \delta_q$ then the level of period 2 sales of the new product is given by equation (21).

Having characterized the optimal production levels, we now examine how they vary with the structural parameters of the model and contrast these results with those derived earlier in the case of separate production. One immediate point of contrast is that, with a joint production/buy-back policy, $q_{1, o}^*$ is independent of $\delta$ and is, therefore, not affected by the higher margin that the firm can earn on the new product. That is, regardless of the value of $\delta$, the firm *always* sells the old product in period 1. This contrasts sharply with the case under separate production when large $\delta$ values force the firm to forego selling the old product even though consumers value the current generation of the product. Further, under a joint production/buy-back strategy when $\gamma = 1$, equation (19) reduces to the expression for $q_1$ in the basic model. In contrast, under separate production such a result would require $\gamma = 1$ and $\delta = 0$ (i.e., the two products

---

\(^8\) If $\delta < \delta_q$ under separate production with buy-backs, then $q_{1, o}^* = 0$ and the firm sells the quantities given by the separate production model.

\(^9\) If $\delta > \delta_b$, then separate production with buy-backs is equivalent to the joint production/buy-back strategy.
would have to be identical). This contrast results from the fact that the optimal first-period sales strategy is independent of \( \delta \) under a joint production/buy-back policy.

In addition, we find that \( q_{t,0}^* \) moves unambiguously higher with the degree to which products compete with one another, \( \partial q_{t,0}/\partial \gamma > 0 \). This again contrasts with the case of the separate production equilibrium in which the effect of changing \( \gamma \) on first-period production depends on the relative magnitude of \( \alpha \) and \( \delta \). In order to understand these results, it is useful to focus on the firm’s strategy with respect to the old product in the second-period, \( q_b \), and see how the sales strategy varies with the structural parameters of the model.

The firm’s decision to sell additional units of the old product in period 2 or to buy-back some of its earlier sales depends on the value of \( \delta \). When \( \delta < \delta_b \), then \( q_b^* < 0 \) and the firm concurrently sells the old and new products. In this case, the comparative statics are in reference to additional sales of the old product in period 2. Although \( q_{t,0}^* \) is independent of \( \delta \), \( q_b^* \) varies with both \( \delta \) and \( \gamma \), with \( \partial q_b^*/\partial \delta > 0 \) and \( \partial q_b^*/\partial \gamma > 0 \). When the firm precommits to phasing out sales of the old product in period 2 and it does not have a buy-back policy, then there is a tradeoff across the two time periods between sales of the old and new products. In contrast, when the firm concurrently sells the two products in the second-period or buys back sales of the old product, the tradeoff between sales of the old and new versions occurs within the second period between \( q_b \) and \( q_{t,n} \).

First, consider the case where \( \delta < \delta_b \) and the firm concurrently sells the old and new products in period 2. A higher level of \( \gamma \) makes the old product relatively more valuable to consumers and increases the price they are willing to pay. On the other hand, an increase in \( \gamma \) raises the cost of cannibalization. When the firm is able to sell the old product in both periods, it is able to respond separately to these effects. Thus, with an increase in \( \gamma \), the firm exploits consumers’ greater willingness to pay in period 1 by selling more of the old product. In period 2, the firm responds to the larger cannibalization cost associated with a higher \( \gamma \), by reducing its sales of the old product. The intuition is similar if \( \delta > \delta_b \) and in period 2 the firm buys back some of its earlier sales of the old product. Again, an increase in \( \gamma \) raises the selling price in period 1. However, a higher level of \( \gamma \) also increases the level of cannibalization. The firm responds to the increase in \( \gamma \) by exploiting the higher first-period price and sells additional units of the old product in period 1. In addition, the firm mitigates the cannibalization of new product sales by buying back more units of the old version in period 2. Thus, regardless of the value of \( \delta \), the firm is able to decouple its response to the change in the relative costs of waiting and cannibalization caused by the change in \( \gamma \). Without a buy-back policy and the ability to sell the old product in period 2, the firm incorporates these tradeoffs in its sales decision regarding the old product in period 1.

Similarly, in the context of changes in the magnitude of the perceived improvement of the new product, controlling the quantity of the old product in both periods allows the firm to decouple the effect of the cost of waiting for period 2 sales and the cost of cannibalization of new product sales. Cannibalization of sales of the new product depends on the total quantity of the old product available in period 2. An increase in \( \delta \) raises the cost of cannibalization, because each unit sale lost of the new product now has a higher price. This suggests that the firm should decrease its higher cost of cannibalization associated with a larger \( \delta \) by decreasing the quantity of the old product available in period 2. Under a separate production strategy, the firm does this by decreasing \( q_{t,0}^* \). However, with a joint production/buy-back policy, the firm can achieve this result by producing less of the old product or buying back more of it in period 2. This allows the firm to reduce the cost of cannibalization without foregoing period 1 profits. When the old product can be sold or bought back in period 2, changes in \( \delta \) do not affect \( q_{t,0}^* \) and are reflected fully in changes in \( q_b^* \).
This discussion illustrates the flexibility permitted the firm if it controls in period 2 the amount of the old product that is available to consumers. This flexibility results from the ability to sell additional units of the old product or buy-back some of its earlier sales. This, in turn, would seem to suggest that the opportunity to engage in joint production and buy-backs makes the firm better off. However, this intuition is only partially correct.

Separate vs. joint production. If \( \delta < \delta_0 \), then \( q^*_b < 0 \) and the firm concurrently sells the old and new versions of the product in period 2. Additional sales of the old product have two effects. Not only do they cannibalize sales of the new version, they lower consumers' expectations in period 1 of the price of the old product in period 2. Consumers expect a lower price in the future because of obsolescence and further saturation of the market due to sales of the old as well as the new products. Therefore, they are willing to pay a lower price for the old product in period 1. With precommitment to a separate production strategy, consumers expect a lower price in the future only because of obsolescence. Thus, the ability to sell additional units of the old product in period 2 has the adverse effect of lowering the price that consumers are willing to pay for the old product in period 1. Consumers' expectation that the firm will dump the old version on the market at a low price reduces their willingness to pay in period 1. More formally, we have the following proposition.

**Proposition 2.** Profits under separate production are higher than profits under joint production.

Thus, the model suggests that the firm can benefit from phasing out the older version of a product once the new version is introduced. The motivation for this is to increase the value to consumers of the old product in period one and to protect the market for the new product.

Separate production vs. buy-backs. Now consider the setting in which \( \delta > \delta_0 \), and the firm buys back some of its earlier sales, \( q^*_b > 0 \). By buying back some of its period 1 sales of the old product, the firm can protect the market for the new version without foregoing revenues in period 1. Each unit of the old product that the firm buys back increases the market for the new product by \( \gamma \). In order to get an equivalent increase in the market for the new product, the firm has to buy-back a greater number of units of the old product. If the quantity of buy-backs is \( q_b \), then the decrease in unit cannibalization is \( \gamma q_b \).

The firm faces a tradeoff between protecting the market for the new product by buying back some of its earlier sales and the cost of these buy-backs. The net effect on the firm's profitability depends on the cost of buying back and the gain in revenues from additional sales of the new product. For a given \( q_{1,o} \), suppose the firm buys back one unit of the old product in period 2. The cost of this buy-back is \( p_b \), the second hand market price. With one buy-back, the decrease in unit cannibalization is \( \gamma q_b \). Whether a buy-back policy is profitable depends on the difference between \( p_b \) and \( \gamma p_{2,n} \). This, in turn, depends on the absolute demand advantage, \( \delta \), of the new product. Since \( \partial p_b / \partial \delta < 0 \) and \( \partial p_{2,n} / \partial \delta > 0 \), there is a cutoff value of \( \delta \) such that a buy-back strategy is less profitable for \( \delta \) values below this cutoff and more profitable for \( \delta \) values above the cutoff.

**Proposition 3.** Profits under a buy-back strategy are higher than profits under separate production if and only if \( \delta > \delta_{11} \), where

\[
\delta_{11} = \frac{\alpha \left[ (\sqrt{6} - \gamma)^2 - \gamma (\sqrt{6} - \gamma - \gamma^2 + 1) + 2 \gamma^2 - 1 \right]}{5(1 + \gamma)}.
\]

Equation (24) is for \( \rho = 0 \). With a positive discount rate, there still exists a cutoff value of \( \delta \) with this property, but the exact characterization is more complex.
When $\delta$ is small, the firm earns higher profits if it does not have a buy-back policy. This result is best understood by looking at the difference between $P_b$ and $\gamma p_{2,n}$. A small $\delta$ means that the loss in value due to obsolescence of the old product is low. Thus, the buy-back price and the selling price of the new product are not very different, and, with $\gamma < 1$, the cost of buying back old units is greater than the benefits of enhancing sales of the new version. Alternatively, when $\delta$ is large, the loss in value of the old product due to obsolescence is large and the increase in value of the new product is also large. Therefore, with a large $\delta$, the firm earns higher profits if it has a buy-back policy.

In summary, the effect of a joint production/buy-back policy depends on $\delta$. There are three regions of $\delta$ that have been identified.

For $\delta < \delta_b$, $q_{b}^{*} < 0$ and the firm concurrently sells the old and new versions of the product in period 2. In this case, the firm would earn higher profits under a strategy of separate production by precommitting not to sell the old product in period 2. As $\delta$ increases beyond $\delta_b$, the firm stops selling the old product in period 2 and begins buying back period 1 sales. When $\delta \geq \delta_q$, then the firm buys back all its period 1 sales of the old product, $q_{b}^{*} = q_{1,o}$, and the level of sales of the new product is $\alpha + \delta / 2\beta$. Finally, we compare the profitability of a buy-back policy versus separate production. For $\delta_b \leq \delta \leq \delta_q$, the firm earns higher profits if it can commit to not having a buy-back policy. For $\delta > \delta_q$, the firm earns higher profits with a buy-back policy.

The cutoff values of $\delta$ for the regions that have been identified vary with the degree of competitive interaction, $\gamma$, between the old and new products. In particular, the values of these cutoffs decrease with $\gamma$. We show in Table 1 the cutoff values of $\delta$ expressed as a ratio of $\delta$ to $\alpha$ for different values of $\gamma$ and a zero discount rate.\textsuperscript{11} The ratio, $\delta / \alpha$, represents the relative increase in the demand associated with the new product. Recall that, with an increase in $\gamma$, the degree of cannibalization of new product sales increases and the firm reduces the quantity of the old product available in period 2. Consistent with this is our result that the cutoff values of $\delta$ decline with $\gamma$. For example, a decrease in $\delta_b$ lowers the range of $\delta$ values under which the firm engages in joint production. Eventually, increases in $\gamma$ drive $\delta_b$ to zero. That is, beyond some $\gamma$ value, the firm does not engage in joint production. For higher $\gamma$ values, $\delta_q$ goes to zero and a buy-back policy becomes more profitable than separate production for all $\delta$ values. Finally, when $\gamma = 1$ then $\delta_q$ goes to zero and, regardless of the value of $\delta$, the firm buys back all its prior sales of the old product.

\textsuperscript{11} A positive discount rate raises the values of the cutoffs without affecting their order.
DURABLE GOODS AND PRODUCT OBSOLESCE

TABLE 1

Cutoff Values of $\delta$ with Zero Discount Rate, Varying $\gamma$

<table>
<thead>
<tr>
<th>$\gamma$</th>
<th>$\frac{\delta_b}{\alpha}$</th>
<th>$\frac{\delta_e}{\alpha}$</th>
<th>$\frac{\delta_q}{\alpha}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.25</td>
<td>0.29</td>
<td>1.38</td>
</tr>
<tr>
<td>0.1</td>
<td>0.17</td>
<td>0.20</td>
<td>1.13</td>
</tr>
<tr>
<td>0.2</td>
<td>0.11</td>
<td>0.13</td>
<td>0.92</td>
</tr>
<tr>
<td>0.3</td>
<td>0.06</td>
<td>0.08</td>
<td>0.75</td>
</tr>
<tr>
<td>0.4</td>
<td>0.03</td>
<td>0.05</td>
<td>0.59</td>
</tr>
<tr>
<td>0.5</td>
<td>0.01</td>
<td>0.02</td>
<td>0.46</td>
</tr>
<tr>
<td>0.6</td>
<td>0.0</td>
<td>0.01</td>
<td>0.35</td>
</tr>
<tr>
<td>0.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.25</td>
</tr>
<tr>
<td>0.8</td>
<td>0.0</td>
<td>0.0</td>
<td>0.15</td>
</tr>
<tr>
<td>0.9</td>
<td>0.0</td>
<td>0.0</td>
<td>0.07</td>
</tr>
<tr>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

4. Uncertain Product Introduction

We now explore the situation in which consumers are uncertain in period 1 whether a new product will be introduced in the subsequent period. It is plausible that consumers' uncertainty is more related to the size of the expected innovation rather than the introduction itself. For example, consumers might be certain that a new product will be introduced, but are uncertain about the amount of improvement and the extent to which the new and old version will compete with one another. We simplify the issue by looking at only the probability of a new product introduction. The effect of this uncertainty is reflected in consumers' expectations of the decrease in price of the old product in the future. Specifically, the greater the likelihood that the firm will introduce a new product, the less consumers are willing to pay for the old product due to a greater threat of a loss in value due to obsolescence.

An important question for firms is whether they should signal to consumers that a new product is forthcoming the next period. In terms of the economics of information, this question can be expressed as whether a pooling or sorting equilibrium is more profitable for the firm (Rothschild and Stiglitz 1976). A pooling equilibrium occurs when the firm provides no information to consumers and, therefore, consumers must rely on their prior beliefs about the likelihood of a new product introduction. In contrast, a sorting equilibrium occurs when the firm signals to consumers whether a new product is forthcoming. In addition, it is important to consider how the firm can credibly convey this information. Firms may have an incentive to always tell consumers that no new product is forthcoming in order to elicit greater demand for the old product in period 1. Simply stating to consumers whether a new product is forthcoming cannot be relied on to be a truthful representation of the firm's actual prospects.\(^{12}\)

\(^{12}\) If one developed a multi-period model, a firm's concern with its reputation could force it to communicate truthfully its prospects in the early stages of the relationship (see Kreps and Wilson 1982 and Milgrom and Roberts 1982 for work along these lines).
However, the firm’s information can be credibly conveyed by its first-period sales and price. Consumers can examine whether the firm’s pricing decision is consistent with that of a firm planning to introduce a new product in the subsequent period. Is the firm using a price skimming strategy to take advantage of consumers with high reservation prices and, in effect, protecting the market for its new product? Or is it setting a lower price in order to encourage consumers to buy now because there will not be a new product forthcoming in the following period?

We assume that there is asymmetry in information between the firm and consumers as to their knowledge of the likelihood of a new product being introduced, with the firm being better informed. The probability of a new product being developed is represented by \( \mu \). Consumers are assumed to know the true frequency with which new products are developed, but not to know the actual success or failure of the product development effort in any particular period. For simplicity, we assume an extreme form of asymmetry in which the firm discovers the success of the product development effort one period earlier than this is observable to consumers. We explore the effect of consumers’ uncertainty under the separate production and joint production/buy-back models. Under both these cases, we find that the firm does better if it informs consumers about forthcoming products.

4.1. Uncertainty and Separate Production

In this setting, the firm sells the old product in period 1 and, if a new product has been successfully developed, it exclusively sells this new product in the second-period. In the absence of a new product, the firm continues to sell the original product in period 2.

In a sorting equilibrium, there are two possible sales strategies. If there is no new product, the firm sells the quantity levels given by the basic model in equations (4) and (5). If the product development effort is successful, the firm sells the quantity levels given by the separate production strategy, equations (13) and (14). If the probability that there is a new product is \( \mu \), the expected profits in a sorting equilibrium are:

\[
\Pi_{\text{sorting}} = (1 - \mu)\Pi_{\text{basic}} + \mu\Pi_{\text{separate}}
\]

where \( \Pi_{\text{basic}} \) and \( \Pi_{\text{separate}} \) are the profits in the basic model and the separate production regimes respectively.

Alternatively, consider the situation in which the firm does not reveal any information in period 1 and consumers do not find out until the second-period whether there is a new product. Obviously, the firm’s choice of second-period sales depends on whether or not a new product was developed. Let the first-period sales of the old product be represented by \( q_{1,o} \). The optimal sales strategy in period 2 in the absence of a new product and given the successful development of a new product is respectively

\[
q_{2,o} = \frac{(\alpha - \beta q_{1,o})}{2\beta},
\]

\[
q_{2,n} = \frac{[(\alpha + \delta) - \beta q_{1,o}]}{2\beta}.
\]

The price that consumers are willing to pay for the old product in period 1 incorporates their uncertainty about the decrease in the product’s price in period 2. If a new product is successfully developed, then the price in period 2 reflects the decrease due to obsolescence. If the probability of a new product is \( \mu \), the selling price in period 1 is

\[
p_{1,o} = (\alpha - \beta q_{1,o}) + (1 - \mu) \frac{(\alpha - \beta q_{1,o})}{2(1 + \rho)} + \mu \left[ \frac{(\alpha - \delta) - \beta q_{1,o}(2 - \gamma)}{2(1 + \rho)} \right].
\]

Note that an increase in \( \mu \) increases consumers’ expectations of a price decrease and, thus, lowers the price that they are willing to pay for the product in period 1.
The problem of the firm is to maximize expected profits.

\[ \text{Max } \Pi_{q_1,0,q_2,0} = p_{1,0}q_{1,0} + (1 - \mu) \frac{p_{2,0}q_{2,0}}{(1 + \rho)} + \mu \frac{p_{2,0}q_{2,n}}{(1 + \rho)}. \]  

(28)

The solution to this maximization problem yields

\[ q_{0,0}^* = \frac{2\alpha(1 + \rho) + \mu(\alpha - \delta) - \mu\gamma(\alpha + \delta)\beta[(5 + 4\rho) + 3\mu - 2\mu\gamma - \mu\gamma^2]}{2\beta(\gamma + 1)}. \]

(29)

The optimal sales strategy in the second-period is given by equation (27) if a new product is developed and, in the absence of a new product, by equation (26).

Consider how the first-period sales policy is influenced by the prospect of a new product in period 2. When there is zero probability of a new product, cannibalizing the new product’s sales is not an issue and, consequently, the firm sells a large volume in period 1. This quantity is given by the basic model or, equivalently, the pooling model with \( \mu = 0 \). On the other hand, when it is known that there is a new product, \( q_{1,0} \) is relatively small in order to minimize cannibalization of new product sales. This value is given by the separate production model or the pooling model with \( \mu = 1 \). Since \( \frac{\partial q_{0,0}^*}{\partial \mu} < 0 \) in the pooling model, we can establish the following relationship regarding sales of the product in period 1:

\[ \text{Basic}_{q_1} > \text{Pooling}_{q_1,0} > \text{Separate Production}_{q_1,0}. \]

We started this section by asking whether the firm has an incentive to reveal to consumers in period 1 whether a new product is forthcoming in the second-period. Having characterized the firm’s sales policy, we can now address this question.

**PROPOSITION 4.** Under a separate production strategy, the sorting equilibrium dominates the pooling equilibrium.

In order to obscure its information in the pooling equilibrium, the firm must distort its sales policy in period 1 by selling too much when the product development effort is successful and too little when it is unsuccessful. In addition, consumers’ uncertainty about future price decreases is incorporated into their demand for the product in the first-period. One might reasonably conjecture that with a sufficiently high discount rate these distortions might be compensated for by the benefits the firm would obtain by keeping consumers uninformed of a forthcoming new product. In particular, if the firm knew that a new product was forthcoming but could have consumers believe that such a development is unlikely, it could generate more earnings in the first-period and a high discount rate would place a relatively large weight on this effect. However, as the discount rate increases, the difference diminishes between the firm’s period 1 earnings when it is known that a new product is forthcoming and when this is uncertain. In the limit, with an infinite discount rate, the firm would act as a myopic monopolist and there would be no difference in earnings in the two situations. It is due to this dual effect that this proposition holds regardless of the value of the discount rate or the probability of a new product being developed. However, the difference in profits between the two equilibria does decrease with the discount rate as more emphasis is placed on period 1 production.

The spread in profits between the pooling and sorting equilibria increases with \( \delta \), as \( q_{0,0}^* \) becomes more sensitive to the introduction of a new version. The divergence between the firm’s optimal level of period 1 sales when it is known that a new product is forthcoming and when it is known that no new product is forthcoming increases with \( \delta \). Under a sorting equilibrium, the larger the improvement of the new product over the old, the more first-period sales are reduced to protect the market for the new product. Therefore, the requirement imposed by the pooling equilibrium of having the same
period 1 sales policy regardless of whether a new product is forthcoming is more constraining with higher values of $\delta$. Thus, the greater the magnitude of improvement of the new product over the old, the larger the difference between profits in the sorting and pooling equilibria. An analogous result holds with respect to $\gamma$. If increasing $\gamma$ reduces the optimal value of $q_{1,o}$, then the spread between the sorting and pooling equilibria increases. Alternatively, if increasing $\gamma$ increases $q_{1,o}^*$, then the spread in profits between the two equilibria decreases.

### 4.2. Uncertainty and Joint Production/Buy-Backs

In this section, we explore the question of signalling when the firm is able to control the level of the old product available in period 2 through concurrent sales or buy-backs. One may reasonably conjecture that this flexibility allows the firm to mitigate the adverse effects associated with consumers’ uncertainty. In particular, in a pooling equilibrium, the firm is hurt by the fact that its sales in period 1 of the old version are too high when a new product is introduced in the second-period. However, with buy-backs, the firm can compensate by buying back some of the excess sales.

In a sorting equilibrium the sales levels are given either by the basic model (if a new product is not developed) or by the joint production/buy-back model (if a new product is developed). The profits under a sorting equilibrium are the expected profits of these two cases. In a pooling equilibrium, the firm provides no information and consumers do not discover until period 2 if a new product has been successfully developed. Thus, with a new product the firm sells $q_{2,n}$ (equation (21)) and buys-back or sells $q_b$ of the old product (equation (20)), and without a new product, it sells $q_{2,o}$ (equation (5)). Consumers incorporate their uncertainty about the price of the old product in period 2 into the price they are willing to pay for the old product in period 1.

Thus, the problem of the firm is to maximize profits.

$$\text{Max } \Pi = p_{1,o}q_{1,o} + (1 - \mu) \frac{p_{2,o}q_{2,o}}{1 + \rho} + \mu \left( \frac{p_{2,o}q_{2,n} - p_bq_b}{1 + \rho} \right).$$  

The solution to this maximization problem yields

$$q_{1,o}^* = \frac{2\alpha(3 + \gamma)(1 + \rho)}{\beta(5 + 4\rho)(3 + \gamma) + \mu\beta(1 - \gamma)}.$$  

Note that when $\mu = 0$ (and, therefore, $\gamma = 1$), then the expression for $q_{1,o}^*$ is the same as the basic model. When $\mu = 1$, then the expression is the same as the joint production/buy-back model. The relationship between the optimal quantity values and the probability of a new product is the same as in the case of separate production. That is, $\partial q_{1,o}^*/\partial \mu < 0$ and Basic$_{q_{1,o}} \geq$ Pooling$_{q_{1,o}} \geq$ Buy-Back$_{q_{1,o}}$.

**Proposition 5.** Under a joint production/buy-back strategy, the sorting equilibrium dominates the pooling equilibrium.

Since the firm has the flexibility of controlling the amount of the old product available in period 2, the optimal first-period sales are independent of $\delta$ and the effect of $\delta$ is incorporated into the second-period sales of the old product or the buy-back policy. The difference in profits between the sorting and pooling equilibria is independent of $\delta$ and is determined by $\gamma$. This difference in profits decreases with $\gamma$ and is zero for $\gamma = 1$.

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13 From Proposition 1, the effect of a change in $\gamma$ on $q_{1,o}^*$ can be positive or negative depending on whether $\delta$ is relatively small or large.
As $\gamma$ increases toward 1, the distortion in $q_{1,0}^*$ associated with the pooling equilibrium diminishes and the profits under the two policies become equivalent.

5. Conclusions

This paper has focused on the effects of obsolescence which occur when a firm introduces an updated version of its product. The extent of obsolescence is related to the size of the improvement in the new product and the degree of competitive interaction between the products. Prior research on firms' sales strategies has used durability as a proxy for obsolescence. However, obsolescence involves much more than just durability: "it is also and perhaps primarily about how often a firm will introduce a new product, and how compatible the new product will be with older versions," (Bulow 1986, p. 747). This paper offers a more complete view of obsolescence, since it models the introduction of a new product defined explicitly by its degree of improvement and its competitive interaction with the older version.

Under a policy of separate production the firm precommits to phasing out the earlier version of the product subsequent to the introduction of the new one. We find that as the degree of product improvement represented by the new product increases, the firm decreases its sales of the old product. For a sufficiently large improvement, the firm chooses not to sell the old version at all. This is similar to leapfrogging behavior on the part of consumers, where they forego adopting the version currently available in favor of a forthcoming new product. In our model, the firm phases out the old product to decrease its cannibalization of new product sales.

There are two ways in which the firm can control the quantity of the old product available in period 2: joint production and buy-backs. With a joint production/buy-back strategy, regardless of the degree of improvement in the new product, the firm always sells the old product in period 1. Joint production of the old and new products appears attractive since the firm can exploit the residual demand for the old product in the second-period. However, since consumers anticipate the resulting decline in the price of the old product, the firm is better off if it can commit to phasing out production of the old product in period 2. The second means of controlling the quantity of the old product available in period 2 is through buy-backs. Buy-backs allow the firm to enhance the level of sales of the new version without having to forego revenues in period 1. A buy-back policy in the form of trade-ins is often used by firms, since trade-ins encourage consumer migration to higher items in the product line. For example, camera manufacturers have offered trade-ins to encourage consumers to purchase new, automatic 35 mm cameras (Wall Street Journal 1987). Our model suggests that a buy-back policy is profitable only when the degree of improvement in the new product is large since this results in a high cost of cannibalization and a relatively low buy-back price.

Finally, we address the effect of uncertainty with consumers having only some probabilistic beliefs about the possible introduction of a new product. We find that the firm earns higher profits if it informs consumers about forthcoming products. When the firm does not inform consumers about a forthcoming product, its sales strategy in period 1 is affected, selling too much of the old product when a new product is successfully developed and too little when the product development effort is unsuccessful.

The model is developed with respect to a monopolist firm and is, therefore, directly applicable for markets in which one firm dominates (e.g., IBM in mainframe computers and Xerox in copiers in the latter 60's and the 70's) and in areas where a firm holds a patent advantage (e.g., Polaroid). However, incorporating competition should not affect the general results regarding an intertemporal tradeoff in choice of sales strategy between increasing current sales and cannibalizing future ones. What is critical
That the innovating firm view its current sales and new product introduction strategy as having an influence on future prices. In contrast, noninnovating firms are less concerned about cannibalizing sales, since an increase in current sales decreases the potential size of the innovating firm's market in the future. Therefore, the analysis is not applicable to perfectly competitive markets, but is suggestive for innovating firms in oligopolistic and monopolistic industries. For example, IBM's share of the personal computer market has slowly been eroded by producers of clones. One of the options available to IBM is to "continuously update its PC's which would make the clones obsolete and improve prices for [new] IBM products," (Business Week 1986, p. 66). However, the cost of this action would make existing inventories of PC's obsolete and clog the dealer channel. In addition to making the existing inventories obsolete, our model suggests that if IBM products are continuously updated, the market for new products will sustain a lower price. In future work we intend to explore the sales strategies of innovating and noninnovating firms in an oligopolistic environment.

Also sensitive to the assumption of a monopoly producer are the results regarding signalling to consumers the prospect of a new product being introduced. In a competitive setting, the incentive to deceive consumers is changed since a firm is affecting its competitor's sales as well as its own. A classic example is IBM's announcement of its model 360/91 in 1964 just before CDC delivered its model 6600. This announcement of a forthcoming model delayed orders for the 6600 and forced CDC to cut its price substantially (Brock 1975). Further extensions of this work should explore the effect of product announcements in a world with multiple firms.

Another important extension would be to make the process of product innovation endogenous. As with prior research on consumers' decision to adopt a product with changing technology (e.g., McCardle 1985; Weiss 1987), we treat the development of the new product as exogenous. An endogenous innovation process is an important means by which the degree of competition among firms affects the nature of a firm's sales strategy. Such a model would bring together research on firms' incentives to invest in product innovation (e.g., Dasgupta and Stiglitz 1980a, b; Reinganum 1981, 1982) with models of firm's sales strategy and consumer adoption decisions.

Finally, it is important to subject our theoretical analysis to an empirical test. While a direct test of the model may be difficult, tests of some of the implications of the model should be both feasible and interesting. For instance, the loss in value of an older version due to obsolescence should be reflected in the second hand market price of the product. That is, the depreciation rates of these products should be influenced by the degree of change in subsequent versions of the product. Any product category for which there exists an active second hand market and frequent product innovations provides an opportunity to test for obsolescence effects. For example, the automobile industry with its well established annual model changes and large second hand market is a potentially attractive setting in which to test some of these implications.  

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14 This paper was received in March 1987 and has been with the authors 2 months for 2 revisions.

### Appendix

**Characterization of Buy-Back Equilibrium**

Suppose that the firm sells $q_{0,t}$ of the old product in period 1. Given this quantity, it must decide in period 2 on the level of sales of the new product and whether to engage in joint production or buy-backs of the old product. Let $q_b$ represent the level of buy-backs or additional sales of the old product in period 2. That is, a positive value of $q_b$ is interpreted as buy-backs of the old product in period 2, and negative values as additional sales of the old product in period 2. Thus, the period 2 problem is stated as

$$\max \Pi_{q_b,A_2} = -p_b q_b + p_2 A_2$$  (32)
subject to \( q_b \leq q_{1,0} \), where

\[
p_b = \alpha - \beta (q_{1,0} - q_b + q_{2,0}), \quad p_{2,n} = (\alpha + \delta) - \beta (\gamma q_{1,n} - \gamma q_b + q_{2,n}).
\]

The reaction functions from this maximization problem are

\[-2\beta q_b + (1 + \gamma)\beta q_{2,n} = \alpha - \beta q_{1,0}, \quad -(1 + \gamma)\beta q_b + 2\beta q_{2,n} = (\alpha + \delta) - \gamma q_{1,0}.
\]

Assuming that the constraint is not binding and solving these equations for \( q_b \) and \( q_{2,n} \), gives their optimal values given some \( q_{1,0} \):

\[
q_b = \frac{\delta (1 + \gamma) - \alpha (1 - \gamma) + \beta q_{1,0} (2 - \gamma - \gamma^2)}{\beta [4 - (1 + \gamma)^2]}, \quad q_{2,n} = \frac{2 (\alpha + \delta) - 2 \gamma q_{1,0} - (1 + \gamma) (\alpha - \beta q_{1,0})}{\beta [4 - (1 + \gamma)^2]}.
\]

Acknowledgements. We are grateful to the Area Editor and three anonymous reviewers for their comments on earlier drafts of this paper.

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