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R&D and Product Obsolescence

GREGORY E. GOERING, JOHN R. BOYCE
Department of Economics, University of Alaska, Fairbanks, Alaska 99775-0580

and

JAMES M. COLLINS
Department of Business Administration, University of Alaska, Fairbanks, Alaska 99775-0580

Abstract. Claims of "planned obsolescence" have often been made by various consumer groups. Bulow (1986) examined a monopolist's choice of product durability and found that firms who sell their products tend to choose lower durability levels than firms that rent. We argue that the speed of new product development may be a more appropriate proxy for obsolescence than is durability. Reformulating Bulow's model in terms of R&D choice rather than durability choice, we find that sales firms engage in higher levels of R&D than do rental firms. Additionally, we provide an empirical example using data from the copier and computer industries which also suggests a strong positive relationship between the R&D intensity of a firm and the proportion of output sold versus rented.

Keywords. Innovation, obsolescence.

I. Introduction

Economists have long wondered if a monopolist would have any incentive to manufacture products of sub-optimal quality or durability. Claims of "planned obsolescence" have been made by various consumer groups. Bulow (1986) provided an economic rational for planned obsolescence. He showed that a monopolist who sells its output has an incentive to reduce durability below efficient levels to mitigate its commitment problem with consumers.[1] However, as Bulow himself notes "planned obsolescence is much more than a matter of 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." This suggests that the speed of new product development may be a more appropriate proxy for obsolescence than durability.[2,3] We reformulate Bulow's model using research and development (R&D) expenditures rather than durability as a proxy for obsolescence. Our formulation has an additional advantage in that R&D expenditure levels are more easily observed than product durability, and are better measures of firm behavior.

Planned obsolescence can be viewed as the amount of resources a firm is willing to expend on R&D to make an existing version of a product obsolete. The planned obsolescence results of the durability literature suggest a firm that sells its output may be willing to invest a larger amount in R&D in an effort to make the old version of the product obsolete than would a firm that rents its output. Our theoretical model demonstrates that this reasoning is indeed correct, a monopolist will have an incentive to invest more resources in R&D in sales markets than rental markets. We also provide an empirical example, using readily available data from IBM and Xerox, which illustrates this strong (positive) relationship between the R&D intensity of a firm and the proportion of output sold versus rented.

We also show that the more durable the product the less of an incentive a renter has to invest in R&D but that a seller may actually increase R&D as durability is increased. This suggests the durability or quality of the product, which is typically ignored in theoretical specifications, may be an important determinant of R&D effort levels in various industries.

The paper is structured as follows: in the next section we describe the basic product innovation (R&D) model assuming the firm's output is durable. In Section III we examine a renting firm's choice of R&D expenditure level and in Section IV we explore a seller's choice of R&D levels. We then compare a renter to a seller in Section V and show that a seller will spend more on R&D than a renter, i.e., a selling firm has an incentive to speed up the development of new products (planned obsolescence) vis-à-vis a renter. We provide an empirical example in Section VI which supports the conclusions of the theoretical model and illustrates that R&D levels tend to increase as a firm sells a larger proportion of its output. Concluding remarks are presented in Section VII.

II. Basic Model

We begin with the development of Bulow's (1986) two period monopoly framework. For simplicity we suppose the firm faces constant marginal production costs in each period, given by c_1 and c_2. We also assume there is a linear demand for rental services in each period which is a function of the total amount of output in circulation. The inverse demand for services in period one and two are: $p_1 = a - bq_1$ and $p_2 = a - b(\delta q_1 + q_2)$, where q_1 and q_2 are the outputs of the original (old) version of the product in period one and two, and δ is the fraction of first period production which remains for use in period two.

Unlike Bulow (1986) we assume that the product's durability δ is exogenously fixed. Instead, we model product obsolescence by assuming the firm can invest in the research and development of a new product. If the firm is successful in its R&D efforts in period one, it can introduce the new version in the second period, making the old version obsolete. Let x be the amount of R&D effort during the first period.[4] The benefit of R&D effort is uncertain since the firm may or may not be able to successful develop a new product for use in the second period. We assume that the probability fiml will successfully develop a new product is $\theta(x)$, where $\theta(0) = 0$, $\theta'(x) > 0$ and $\theta''(x) < 0$. Thus there are diminishing returns to R&D effort. If the firm is successful it receives the new product which has a constant value v, furthermore we assume the new product renders the old version completely obsolete and its price falls to zero.[5] With probability $1 - \theta(x)$ the research is unsuccessful and the firm continues to produce the old version in the second period.

III. R&D in Rental Markets

In the second period the monopolist will either receive the innovation (new product) or it will continue to produce and rent the old version. Denoting the rental levels of the variables with the superscript r, we know with probability $\theta(x^r)$ the firm's R&D effort is successful. In this case the old version of the product is rendered completely obsolete, implying second period production of the old version is zero ($q_2^r = 0$) and the fum captures profits v. With probability $1 - \theta(x^r)$ the firm is unsuccessful so it continues to produce and rent the old version of the product. If the monopolist is unsuccessful its second period profit is:

$$\Pi_2 = (\delta q_1^r + q_2^r)(a - b(\delta q_1^r + q_2^r)) - c_2 q_2^r,$$

implying that

$$q_2^r = (a - c_2)/2b - \delta q_1^r$$

maximizes its rental profit. Using this relation we can rewrite the firm's second period profit in this case as:

$$\Pi_2(q_1^r) = \frac{(a - c_2)^2}{4b} + c_2 \delta q_1^r.$$

Thus with probability $1 - \theta(x^r)$ the firm is unsuccessful in its R&D endeavor and receives $\Pi_2(q_1^r)$ in period two and with probability $\theta(x^r)$ it is successful and receives v, implying expected second period profits are:

$$E\Pi_2(q_1^r, x^r) = \theta(x^r)v + (1 - \theta(x^r))\Pi_2(q_1^r).$$

Assuming the firm is risk neutral it seeks to maximize its discounted expected profit, which is simply the discounted sum of first and expected second period profit:

$$\begin{aligned} E\Pi(q_1^r, x^r) &= \Pi_1(q_1^r, x^r) + \beta E\Pi_2(q_1^r, x^r) \\ &= (a - bq_1^r - c_1)q_1^r - x^r + \beta\left(\frac{(a - c_2)^2}{4b} + c_2\delta q_1^r\right) \\ &\quad \times (1 - \theta(x^r)) + \beta\theta(x^r)v, \qquad (1) \end{aligned}$$

where β is the discount factor. The durable goods rental monopolist maximizes (1) through its choice of first period production q_1^r and R&D expenditure.

IV. R&D in Sales Markets

The rental solution is dynamically inconsistent if the firm sells its output. The firm has an incentive to increase sales in later periods (vis-à-vis the rental case) since it no longer owns the stock of output. This creates a commitment problem for the monopolist unless the firm can credibly convince buyers that it will not flood the market in future periods. In this section we assume the monopolist cannot credibly commit to consumers and defer discussion of the firm's commitment ability to Section V.

In period two the sales monopolist will continue to produce the old version of the product if its R&D is unsuccessful. Its second period profit in this case is:

$$\Pi_2 = (a - b(\delta q_1^s + q_2^s) - c_2)q_2^s,$$

where the superscript s denotes the sales levels of the variables. A sales monopolist profit maximizing second period output level is:

$$q_2^s = \frac{a - c_2 - b\delta q_1^s}{2b}. \tag{2}$$

We can use (2) to rewrite the firm's second period profit as a function of first period output:

$$\Pi_2(q_1^s) = \frac{(a - c_2)^2}{4b} - \frac{\delta q_1^s(a - c_2)}{2} + \frac{b(\delta q_1^s)^2}{4}.$$

With probability $1 - \theta(x^s)$ the seller is unsuccessful in its R&D effort and captures $\Pi_2(q_1^s)$, and with probability $\theta(x^s)$ it successful introduces the new product and receives v.[6] This implies the film's expected second period profit is:

$$E\Pi_2(q_1^s, x^s) = \theta(x^s)v + (1 - \theta(x^s))\Pi_2(q_1^s). \tag{3}$$

With expected second period profit specified by (3) we can now turn our attention to the monopolist's first period profit.

If consumers are rational they recognize the firm's incentive to flood the market in the second period and as a consequence modify their first period buying behavior. For simplicity we suppose the buyers can observe the R&D activities of the firm and recognize that with probability $\theta(x^s)$ any output sold in the first period will be obsolete in period two.[7] If buyers are also risk neutral the asset (sales) price of the durable good is simply the discounted stream of expected rental prices. Thus the expected asset price of a unit of output with durability δ is:

$$EP(q_1^s, x^s) = a - bq_1^s + \beta\delta(1 - \theta(x^s))\left(\frac{a + c_2}{2} - \frac{b\delta q_1^s}{2}\right). \tag{4}$$

where we have used (2) to eliminate q_2^s. Using (3) and (4) we can write the monopolist's expected profit as:

$$E\Pi(q_1^s, x^s) = (EP(q_1^s, x^s) - c_1)q_1^s - x^s + E\Pi_2(q_1^s, x^s)$$

$$= (a - bq_1^s - c_1)q_1^s - x^s + \beta\left(\frac{(a - c_2)^2}{4b} + c_2\delta q_1^s - \frac{b(\delta q_1^s)^2}{4}\right)(1 - \theta(x^s)) + \beta\theta(x^s)\nu. \quad (5)$$

The risk neutral monopolist will choose its period one sales level q_1^s and R&D effort level x^s to maximize (5).

We now can compare the behavior of a rental and sales monopolist and show that the sales monopolist has a larger incentive to invest in R&D than a rental monopolist.

V. R&D and Planned Obsolescence

Since a sales monopolist does not own the stock of the durable good it has a commitment problem with buyers. Rational consumers recognize that the firm has no incentive to take into account the loss in value of the existing stock held by consumers in its future maximization process. On the other hand, a rental monopolist internalizes this loss in value since it owns the stock of output in all periods, consequently it has no commitment problem. Thus the difference between the rental analysis of Section III and the sales analysis of Section IV can be viewed as the inability of the sales firm to credibly commit to buyers.

The commitment power of a selling firm can be formalized by parameterizing the film's expected profit function. By comparing the expected rental profits (1) and the expected sales profits (5), we see that the profit function for selling firm contains an additional negative term $[-\beta(1 - \theta(x^s))(b(\delta q_1^s)^2/4)]$. This term reflects the inability of a selling firm to commit to buyers. If the selling firm can perfectly commit this term vanishes (a seller can act like a renter). In reality a firm may be able to commit through the use of contracts or repurchase agreements.[8] This suggests we can parameterize a selling firm's commit ability through the use of a scalar γ, where $1 \geqslant \gamma \geqslant 0$. Ignoring the superscripts we can rewrite (5) as

$$E\Pi(q_1, x) = (a - bq_1 - c_1)q_1 - x + \beta\left(\frac{(a - c_2)^2}{4b} + c_2\delta q_1 - \frac{\gamma b(\delta q_1)^2}{4}\right)(1 - \theta(x)) + \beta\theta(x)\nu. \quad (6)$$

If the selling firm has no commitment ability then γ equals one and (6) collapses to (5). On the other hand, if the firm has perfect commitment ability γ equals zero and (6) collapses to the renter's expected profit function (1). Thus as γ increases from zero the firm's commitment ability through contracts or price guarantees is diminished. In other words, as γ decreases from one a seller is able to "act more like a renter."[9]

This notion of commitment provides a convenient tool to compare a seller and renters speed of new product development (level of R&D). Differentiating (6) with respect to first period output q_1 and R&D expenditure level x gives:

$$\frac{\partial E\Pi}{2q_1} = a - 2bq_1 - c_1 + \beta\delta(1-\theta(x))\left(c_2 - \frac{\gamma b\delta q_1}{2}\right) = 0 \tag{7}$$

$$\frac{\partial E\Pi}{\partial x} = \beta\theta'(x)\left(v - \frac{(a-c_2)^2}{4b} - c_2\delta q_1 + \frac{\gamma b(\delta q_1)^2}{4}\right) - 1 = 0. \tag{8}$$

Equation (8) indicates the expected benefit of a unit of R&D effort is the increased probability of successfully capturing the innovation ω minus the loss in profit of the old version. Of course, if the new product has a lower value than producing the old version the lrm would not be willing to expend resources on R&D. Thus in the remainder of the analysis we assume the value v of the new product is large enough to ensure an interior solution ($x \geqslant 0$).

As already noted, if the "commitment parameter" γ equals zero a selling firm has perfect commitment ability and acts like a renter, implying that (7) and (8) collapse to the renter's first order conditions. Thus to compare the R&D levels of a renter and a seller we can implicitly differentiate (7) and (8) with respect to this commitment parameter γ which gives:

$$\frac{\partial x}{\partial \gamma} = \frac{\delta^2\theta'\beta bq_1(4c_2\delta\beta(1-\theta) + bq_1(4 - \gamma\beta\delta^2(1-\theta)))}{8|H|}, \tag{9}$$

where $|H|$ is the determinant of negative definite Hessian matrix. Given that γ, β, δ, and θ are less than or equal to one and $|H|$ is greater than zero, Equation (9) demonstrates $\partial x/\partial\gamma > 0$. Since $\partial x/\partial\gamma > 0$ it implies that a seller increases its level of R&D as its commitment problem with buyers is intensified.

Proposition. As a selling firm's ability to commit to first period buyers is decreased its amount of R&D increases.

Alternatively, as γ decreases from one, a seller's commitment power is increased and the firm can act more like a renter (x^s approaches x^r). Assuming a pure sales monopolist has no ability to commit ($\gamma = 1$) and noting that a pure rental monopolist has "perfect" commitment ability ($\gamma = 0$), we have the following corollary:

Corollary. A seller of a durable good has a larger incentive to make an existing version of its product obsolete then does a renter, implying "planned obsolescence".

This corollary indicates that "planned obsolescence" exists in that durable goods manufactures who sell without commitment power tend to speed up the development and introduction of new products when compared to a renter. The profits of the old version of the product are lower for a seller than a renter due to the seller's commitment problem with consumers. This implies a seller has a larger incentive to make the old version obsolete by introducing a new version of the product. In other words, the loss in profits of a seller of switching to the new product is less than that of a renter, since the seller does not own the stock of the old version. Thus a seller has an incentive to invest more in R&D than a renter in an effort to make the old version of the product obsolete in much the same fashion that it would have an incentive to reduce durability below efficient levels if it sells.

It is also worthwhile to note that the durability of the old output δ affects the R&D behavior of the firm, suggesting that the pace of innovative activity is in large measure dependent upon the durability of the product. By implicitly differentiating (7) and (8) with respect to product durability δ, we see that:

$$\frac{\delta x}{\partial \delta} = \frac{\theta' \beta(\gamma b \delta q_1 - 2c_2)((2c_2 - \gamma b \delta q_1)(1-\theta)\delta\beta + 4bq_1)}{4|H|}. \tag{10}$$

Equation (10) indicates that firms with durable products may be less inclined to expend resources on R&D than those firms with non-durable products if the durable output is *rented*, i.e., when γ is equal to zero $\partial x/\partial \delta$ is negative. Obviously, this is due to the larger profit potential of durable products in our model. The more durable the monopolist's output, the larger the profit margin is on the old version, implying the firm has an incentive to spend less on R&D.[10]

Note that unlike a renter, a seller without perfect commitment ability will not necessarily decrease its R&D as the durability of the product is increased, i.e., the sign of $\partial x/\partial \delta$ is ambiguous if γ is greater than zero. This is due to the dual effect of increased durability in sales markets. Like the rental case, as durability δ increases the "asset" value of the existing version of the good tends to increase since a higher fraction is available for use in the second period. This implies the amount of R&D effort a firm is willing to under take in an attempt to make the existing version obsolete will decrease. However, unlike a renter, a seller's commitment problem is also increased as δ increases, implying the value of the existing old version is reduced. This tends to increase the incentive for R&D. Thus whether or not a seller's R&D effort will increase or decrease as the good becomes more durable depends upon the strength of these opposing forces.

VI. An Empirical Example

To provide an empirical illustration of the model developed above we examined the rental, sales, and R&D activities of two large well-known American manufac-

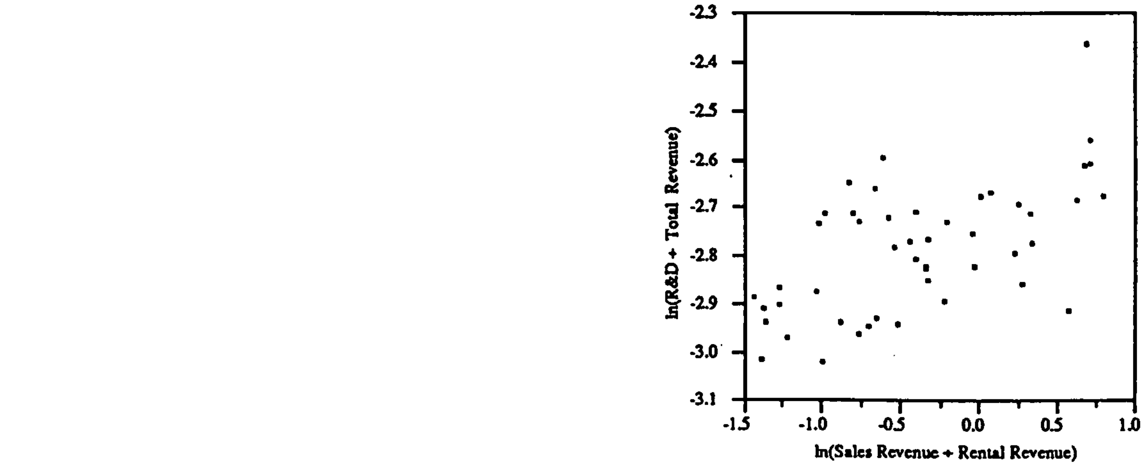

Fig. 1. Relationship between R&D intensity and the sales-rental revenue ratio for IBM and Xerox.

turers of durable goods, IBM and Xerox, over the period 1967–1990. Unlike product durability, R&D expenditure levels, as well as rental and sales revenues, are readily obtained from the firms' annual reports and 10-K statements. Thus the use of R&D expenditure levels as a proxy for product obsolescence is more amenable to empirical exploration than product durability or quality. Note that the corollary presented in Section V, as well as the discussion in the appendix, suggests that the ratio of sales to rentals may be considered an alternate form of the commitment parameter γ. As (9) indicates, there is a positive relationship between γ and R&D levels. Thus we would expect the sales-rental revenue ratio to vary directly with the level of R&D expenditures or intensity.

To form a R&D intensity measure, as is typical in the literature, we normalized each firm's R&D expenditures by total firm revenue.[11] Additionally, the two firms' time-series were pooled, giving a total of $n = 48$ observations. Figure 1 presents a graphical illustration of the relationship between the sales-rental ratio and R&D intensity in logs. Clearly, a positive relationship is indicated, an outcome which is consistent with the conclusions of the theoretical model.

Figure 1 suggests that if firms sell a larger fraction of their output their R&D levels will tend to increase. To examine the significance of the relationship, the following simple linear model was estimated via ordinary least squares:[12]

$$\ln\left(\frac{\text{R\&D}}{\text{Total Revenue}}\right) = \tau_1 + \tau_2 D + \tau_3 \ln\left(\frac{\text{Sales Revenue}}{\text{Rental Revenue}}\right) + e.$$

In this formulation D is simply a dummy variable representing firm identity, with IBM denoted as one.[13] The estimated parameters and regression statistics are presented in Table I.

Table I. Parameter estimates

$R_2 = 0.46$, $n = 48$

Parameter	Estimate	Standard error	t-statistic
τ_1	−2.79079	0.02553	−109.30*
τ_2	0.09185	0.03118	2.95*
τ_3	0.09739	0.02416	4.03*

* Significant at the 1% level.

In Table I, all estimates are significant at the 1% level and, in particular, the coefficient of the logged sales-rental ratio τ_3 is highly significant and of the expected sign ($\tau_3 > 0$). Additionally, the significant coefficient associated with the dummy variable indicates a difference between the firms (cross-sectional units), as one would expect, with IBM exhibiting increased R&D intensity relative to Xerox ($\tau_2 > 0$).

In summary, the results presented in Table I and Figure 1 clearly indicate that, in the context of this simple exploratory example, as a firm sells a large fraction of its output it tends to invest more heavily in R&D. However, these empirical results are only suggestive in that many other factors might have affected the variables contained in the model. For example, the computer and copier industry are clearly oligopolistic, not monopolistic, implying strategic considerations among rival firms may be important. Additionally, in recent years the Federal government has pressed large dominant firms like IBM to sell a larger proportion of their output. Nevertheless, the example does indicate, whatever the motivation for changes in the sales-rental ratio, such changes vary directly with changes in R&D investment. Thus, in accordance with the theoretical results of Section V, it suggests a selling firm may indeed speed up the development of new products (planned obsolescence) vis-à-vis a renting firm.

VII. Conclusion

We have shown a seller of a durable good would tend to speed up the development and introduction of new products vis-à-vis a renter. Our model indicates this occurs because the value of the existing version of the product is generally less for a seller due to its commitment problem with consumers. Thus "product obsolescence" occurs in that a selling firm tends to introduce new products faster than a renter in an attempt to make existing versions obsolete. This implies that a durable goods manufacture that sells its output, such as the computer chip manufacturer Intel, may have an incentive to "aggressively make its product obsolete" by speeding up the development of new products. An examination of time series data from IBM and Xerox suggests this is indeed the case: as the fraction of output sold versus rented increases firms tend to increase their R&D expenditure levels. We show that this occurs in much the same fashion as a seller of a durable good will reduce the durability of its product below efficient levels.

Our result is important for two reasons. First, it demonstrates existing product obsolescence models can be extended to dimensions other than product durability. Second, data on the durability of firm specific products is difficult to obtain and may depend upon the behavior of the consumers as well as the producers. For example, moral hazard problems associated with rental markets will tend to make goods appear less durable. Using firm R&D expenditure level as a proxy for obsolescence eliminates this problem since it is more readily available. Thus the model we have developed is much more amenable to empirical study.

Appendix

In this appendix we provide an alternative interpretation for the commitment parameter γ. Suppose that the monopolist concurrently rents and sells output in period one, where the exogenous fraction of first period output rented is α and the fraction sold is $1-\alpha$. Then in the second period if the firm is unsuccessful in its R&D endeavor its profit are:

$$\Pi_2 = (a\delta q_1 + q_2)(a - b(\delta q_1 + q_2)) - c_2 q_2, \tag{A1}$$

implying that

$$q_2 = \frac{a - c_2 - b(1+\alpha)\delta q_1}{2b}, \tag{A2}$$

maximizes its profit. Substituting (A2) into (Al) gives:

$$\Pi_2(q_1) = \frac{(a-c_2)^2}{4b} + \frac{\delta q_1((\alpha-1)a + (1+\alpha)c_2)}{2} + \frac{b(\delta q_1)^2(1-\alpha)^2}{4}. \tag{A3}$$

With probability $1-\theta(x)$ the firm is unsuccessful in its R&D effort and captures $\Pi_2(q_1)$ and with probability $\theta(x)$ it successful introduces the new product and receives v. Thus the firm's expected second period profit is:

$$E\Pi_2(q_1, x) = \theta(x)v + (1-\theta(x))\Pi_2(q_1). \tag{A4}$$

Using (A2), the expected asset price of a unit of output which is sold is:

$$EP(q_1, x) = a - bq_1 + \beta\delta(1-\theta(x))\left(\frac{a+c_2}{2} - \frac{b(1-\alpha)\delta q_1}{2}\right). \tag{A5}$$

Of course the revenues that the firm receives in the first period is comprised of the weighted sum of the units sold and rented, thus the firms expected profits in period one are:

$$E\Pi_1(q_1,x) = (\alpha(a-bq_1) + (1-\alpha)EP(q_1,x) - c_1)q_1 - x$$
$$= \left(a - bq_1 + (1-\alpha)\beta\delta(1-\theta(x))\left(\frac{a+c_2}{2} - \frac{b(1-\alpha)\delta q_1}{2}\right) - c_1\right)q_1 - x. \quad \text{(A6)}$$

Using (A4) and (A6) and simplifying gives the monopolist's expected discounted profit:

$$E\Pi(q_1,x) = E\Pi_1(q_1,x) + \beta E\Pi_2(q_1,x)$$
$$= (a - bq_1 - c_1)q_1 - x + \beta\left(\frac{(a-c_2)^2}{4b} + c_2\delta q_1 - \frac{(1-\alpha)^2 b(\delta q_1)^2}{4}\right) \times (1-\theta(x)) + \beta\theta(x)\nu. \quad \text{(A7)}$$

By comparing (A7) with the expected profit function (6) from Section V we see that the commitment parameter $\gamma = (1-\alpha)^2$. Thus an altemative interpretation of γ is in terms of the fraction of its output a firm rents. As the fraction of rentals a approaches zero γ approaches one since the firm's commitment problem with buyers is increased. On the other hand, as the fraction of rentals a approaches one the firm's commitment problem with buyers is eliminated.

Note that we have assumed the fraction of rental α is *exogenously* fixed. If instead α is a choice variable its clear from (A7) that the firm would choose to rent all of its output ($\alpha = 1$) since it can completely mitigate is commitment problems by doing so. However, as Bulow suggests the firm may be forced to sell due to legal restrictions and/or moral hazard problems. Additionally, the firm may wish to concurrently sell and rent if there is a threat of future entry (see Bucovetsky and Chilton (1986)). Bhatt (1989) also argues a firm may prefer to sell if it is risk averse.

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Notes

[1] This commitment problem was first recognized by Coase (1972). Coase argued that consumers expectations about future prices will constrain a monolist's ability to earn above normal profits in sales markets, since consumer recognize a firm has an incentive to cut price in the future (increase output). Note that in rental markets this commitment problem vanishes and planned obsolescence does not

occur (see Schmalensee (1979) for a useful survey and Goering (1992) for an analysis of oligopoly durability choice in rental markets).

[2] This also seems to be the common usage of the term "product obsolescence". For example, Seymour (1991) p. 73 argues that for the computer chip manufacturer Intel to stay on top of the market, it must "aggressively make its products obsolete" by speeding up the development of new chips.

[3] An alternative approach for analyzing the phenomena of planned obsolesecnce is that taken by Purohit and Levinthal (1989), who construct a model in which a sales monopolist costlessly introduces an improved version of the product which competes with the existing version. The authors then examine a variety of strategies on the part of a selling firm such as buy-backs. Our approach differs in that we treat product innovation as an *endogenous* process.

[4] For a good survey of the early R&D literature see Kamien and Schwartz (1982).

[5] This is a strong assumption in that it implies the new version of the product reduces the demand for the old version to zero (total obsolescence). It also implies the value of the innovation is independent of period one production levels. This assumption, however, does not drive our results and model could be modified to allow for some degree of substitutability between old and new output.

[6] Note that we are assuming the value of thc new product is the same for renter and seller. In reality the value of the product innovation v is likely to be a function of whether or not the new product is sold or rented and other future considerations such as the threat of entry. The two period nature of the model allows us to abstract from these complications and focus our attention on the differential R&D incentives of a renter or seller purely as a function of the existing (old) version of the product.

[7] Hence, we are assuming that there is no asymmetry in terms of information, buyers have access to the same information as the seller. In a more complicated framework one could assume that consumers have imperfect knowledge of the R&D activities of the firm and some associated subjective probability that the firm's R&D effort is successful.

[8] For example, Butz (1990) demonstrates that best-price provisions, i.e., a guarantee that buyers will pay the lowest price, is sufficient in certain cases to migate the firm's commitment problem entirely.

[9] Alternatively, the parameter γ can be interpreted in terms of the fraction of its output the firm rents in period one. We demonstrate in the appendix that if α is the exogenous fraction of first period output rented that $\gamma = (1-\alpha)^2$. Thus as the fraction of rentals α approaches zero, γ approaches one and conversely, as fraction of rentals α approaches one, γ approaches zero.

[10] This finding is due in part to the assumption that durability is *exogenously* determined but it does indicate that the conclusion's of patent race RD models, in general, may be sensitive to the products durability (which is typically ignored). See Bond and Samuelson (1987) for the impact of durability on cost-reducing R&D.

[11] See Hay and Morris (1991) for a comprehensive discussion of the empirical R&D literature.

[12] This is, of course, a restricted least squares regression in that the coefficients on sales revenue and rental revenue are assumed to be of equal magnitude but opposite sign when tne sales-rental ratio is used as the explanatory variable. The model could be easily rewritten in a more general (unrestricted) form as:

$$\ln\left(\frac{\text{R\&D}}{\text{Total Revenue}}\right) = \tau_1 + \tau_2 D + \tau_3 \ln(\text{Sales Revenue}) + \tau_4 \ln(\text{Rental Revenue}) + e.$$

This model was estimated and the coefficients of both sales and rentals were significant at the 1% level with $\tau_3 > 0$ and $\tau_4 < 0$ as expected. However, a test of the null hypothesis $\tau_3 = -\tau_4$ could not be rejected at the 5% level, thus we report the restricted version of the model.

[13] See Judge et al. (1988) for a discussion of pooling cross-sectional and time-series data using dummy variables.

References

Bhatt, S. (1989) 'Demand Uncertainty in a Durable Goods Monopoly', *International Journal of Industrial Organization*, **7**, 341–355.

Bond, E. and Samuelson, L. (1987) 'Durable Goods, Market Structure and the Incentives to Innovate', *Economica*, **54**, 1987, 57–67.

Bucovetsky, S. and Chilton, J. (1986) 'Concurrent Renting and Selling in a Durable-Goods Monopoly Under the Threat of Entry', *Rand Journal of Economics*, **17**, 261–275.

Bulow, J. (1986) 'An Economic Theory of Planned Obsolescence', *Quarterly Journal of Economics*, **101**, 729–749.

Butz, D. (1990) 'Durable Good Monopoly and Best-Price Provisions', *American Economic Review*, **80**, 1062–1076.

Coase, R. (1972) 'Durability and Monopoly', *Journal of Law And Economics*, **15**, 143–149.

Goering, G. (1992) 'Oligopolies and Product Durability', *International Journal of Industrial Organization*, **10**, 55–63.

Hay, D. and Morris, D. (1991) *Industrial Economics and Organization*, Oxford: Oxford University Press.

Judge, G., Hill, R., Griffiths, W., Lutkepohl, H. and Lee, T. (1988) *Introduction to the Theory and Practice of Econometrics*, New York: Wiley.

Kamien, M. and Shwartz, N. (1982) *Market Structure and Innovation*, Cambridge: Cambridge University Press.

Levinthal, D. and Purohit, D. (1989) 'Durable Goods and Product Obsolescence', *Marketing Science*, **8**, 35–55.

Schmalensee, R. (1979) 'Market Structure, Durability, and Quality: A Selective Survey', *Economic Inquiry*, **17**, 177–196.

Seymour, J. (1991) 'Intel: Is It Still Inside "The Computer Inside"', *PC Week*, **8**, 73.