An Economic Theory of Planned Obsolescence

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"Planned Obsolescence" is the production of goods with uneconomically short useful lives so that customers will have to make repeat purchases. However, rational customers will pay for only the present value of the future services of a product. Therefore, profit maximization seemingly implies producing any given flow of services as cheaply as possible, with production involving efficient useful lives. This paper shows why this analysis is incomplete and therefore incorrect. Monopolists are shown to desire uneconomically short useful lives for their goods. Oligopolists have the monopolist's incentive for short lives as well as a second incentive that may either increase or decrease their chosen durability. However, oligopolists can generally gain by colluding to reduce durability and increase rentals relative to sales. Some evidence is presented that appears to be generally consistent with the predictions of the theory.

I. INTRODUCTION

Suppliers of durables in imperfectly competitive markets have been suspected of producing goods with uneconomically short useful lives, so that consumers will have to repurchase more often.[1] However, the theory behind "planned obsolescence" has been notably weak.[2] Will customers not pay less for products that have a shorter useful life? If the firm decides to sell customers any given flow of services, does profit-maximizing behavior not imply producing those services as cheaply as possible?[3] These are the questions with which an economic theory of planned obsolescence must deal.

1. See, e.g., Galbraith [1958, p. 352] discussing the wastefulness of changing automobile models. Probably the best known empirical work in this area is Fisher, Griliches, and Kaysen [1962].
2. Martin [1962], Kleiman and Ophir [1966], Levhari and Srinivasan [1969], and Schmalensee [1970] all concluded that monopolists would choose inefficiently short asset lives, but did so via flawed analyses. Barro [1972] relied on consumers and producers facing different discount rates to derive planned obsolescence.
3. See Swan [1972, 1977] and Sieper and Swan [1973] for a detailed presentation of this argument. These papers also showed the errors made by the first several authors cited in footnote 2. For a good survey of the durability literature until 1980, see Schmalensee [1979].

This paper explains why, in a full information model[4] with rational customers, a firm might opt to give its products a shorter than economically desirable useful life. Sometimes firms may even pay *more* to produce a shorter lived asset. The key results of the paper follow:

1. Except under unusual cost conditions[5] a monopolist not threatened by entry will produce goods with inefficiently short useful lives. This result is closely linked to the observation that a durable goods monopolist will prefer to rent, rather than sell its output.[6]

2. An oligopolist, or equivalently a monopolist facing certain entry in a subsequent period, also has a countervailing incentive to extend durability. As a corollary, such firms have an incentive to steer customers to purchase rather than rental contracts. This same result also holds if future competition is to be over a related but not identical substitute product. Therefore, while monopolists will opt for inefficiently short useful lives, oligopolists may choose either uneconomically short or long lives, depending on their technologies and market conditions. There is also an incentive to increase durability to deter entry.[7]

3. There is generally an incentive for oligopolists to collude to reduce durability, below noncooperative levels.

4. While antitrust policy requiring firms to sell rather than rent their products will reduce profitability and any monopoly power, it may also decrease welfare.

In Section II the basic model of a monopolist choosing a durability is developed. While competitive firms will choose the ef-

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4. We mean to rule out equilibria where durability is unobservable prior to purchase, firms have a cost incentive to produce shoddy products, and customers therefore assume that low-durability products will be produced.

5. Specifically, a firm's marginal cost curve having a steeper slope than its demand curve around equilibrium.

6. See Bulow [1982] for an exposition on the advantages of renting for such a monopolist. The link is that by renting the monopolist is selling off the non-durable services of his products and may thus achieve many of the advantages of low durability without the costs of inefficient production. However, there are many durable product markets where rental markets have their own inefficiencies. Consider, for example, the incentive problems in automobile rental. A good paper discussing the lease versus buy question in a competitive environment is Wolfson [1985].

7. There is an extensive literature on increasing the durability of investment assets to deter entry. The analogous point on the demand side is that entry is less profitable if customers are tied to long-term contracts or already own assets with long lives.

ficient level of durability, the monopolist's profit-maximizing rate of durability is shown to equal the efficient level plus a term that is generally negative.

Section III extends the basic model to oligopolies. Oligopolists must add an extra term to the monopolist's durability choice, generally causing them (in quantity competition) to decrease the rate of obsolescence.

Section IV provides illustrations of monopoly and oligopoly durability choice to indicate how an oligopolist or a monopolist facing actual or potential entry will change obsolescence from efficient levels. The monopolist facing entry may choose durability to effectively become a Stackelberg leader in the post-entry period. We also find that an oligopolistic industry can gain by colluding to increase the rate of obsolescence beyond noncooperative levels.

In Section V we examine the strategic consequences to imperfectly competitive firms of renting versus selling. Increasing the sales-rental ratio is the strategic equivalent of increasing durability. This analysis suggests that prior to introducing a new model in an oligopolistic market a firm may choose to sell rather than rent its old units. This incentive exists even though a greater sales-rental ratio with the stock of outstanding units unchanged will lead to a lower sales price. The analysis also predicts that as a monopolist's markets become more competitive, the firm will increase its sales-rental ratio. This prediction is loosely corroborated empirically.

Section VI summarizes and concludes the paper.

II. Monopoly and Planned Obsolescence

We begin by considering a monopolist who is maximizing profits over two periods. In the first period it chooses both a quantity q_1 and a durability δ. Of the initial q_1 units sold, $(1 - \delta)q_1$ disappear at the end of the first period and δq_1 remain in period 2. The firm may also produce an additional q_2 units in period 2. The implicit rental price of a unit in period 1 is $f_1(q_1)$ and the implicit rental price in period 2 is $(1 + r)(f_2(\delta q_1 + q_2))$, where r is the interest rate. Total costs in period 1 are $C_1(q_1,\delta)$, and period 2 costs are $(1 + r)C_2(q_2)$. The present value of second-period revenues is thus $f_2(\delta q_1 + q_2)$, and the present value of second-period costs is $C_2(q_2)$. The firm is required to sell, rather then rent, its

output.[8] Finally, we assume a perfect second-hand market: any first-period purchaser of one unit can resell his remaining δ units in the second period at the market price of new output.[9]

The problem of the monopolist is to

$$
(1) \quad \max_{q_1, q_2, \delta} \pi = q_1 f_1(q_1) + (\delta q_1 + q_2) f_2(\delta q_1 + q_2) \\
- C_1(q_1, \delta) - C_2(q_2),
$$

where the first two terms represent the present value of total revenues and the last two terms are the present value of total costs.

Left unconstrained, the monopolist faces the following first-order conditions:

$$
(2) \quad \frac{\partial \pi}{\partial q_1} = f_1 + q_1 f_1' + \delta f_2 + (\delta q_1 + q_2) \delta f_2' - \frac{\partial C_1}{\partial q_1} = 0
$$

$$
(3) \quad \frac{\partial \pi}{\partial q_2} = f_2 + (\delta q_1 + q_2) f_2' - C_2' = 0
$$

$$
(4) \quad \frac{\partial \pi}{\partial \delta} = q_1 f_2 + (\delta q_1 + q_2) q_1 f_2' - \frac{\partial C_1}{\partial \delta} = 0.
$$

Combining the last two conditions yields

$$
(5) \quad \frac{1}{q_1} \frac{\partial C_1}{\partial \delta} = C_2'.
$$

Condition (5) states that the firm will choose an efficient durability: it equates the cost of making its original units a little more durable so that one more of the original units will still be useful in the second period, $((1/q_1)(\partial C_1/\partial \delta))$, with the present value of the

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8. We also rule out the monopolist's engaging in financial contracts that place him in the equivalent position of a renter. The simplest such contract would be one to repurchase all sold items at a fixed price at the end of one period. Anderson [1984] suggests futures contracts where the monopolist, by holding futures, could internalize changes in the general level of prices while making individual owners responsible for changes in specific asset values due to differing levels of maintenance. One difficulty with such a contract is that it may be difficult for the monopolist to make its net futures market position publicly observable.

9. This assumption has several implications. Combined with the assumption of a downward sloping demand curve, it implies that first-period consumers are made worse off by increased second-period production. Note that sometimes a monopolist may wish to deter the second-hand market; consider a firm that offers tied service contracts to customers which are only valid for the original purchaser of a good. Imperfections in the second-hand market have the effect of reducing the economic durability of a product (see Bulow [1982]).

cost of replacing an extra unit in the second period, (C_2'). This is the conclusion of Swan [1972]: for any given flow of services the monopolist chooses to produce, profit maximization implies that thèse services be produced as cheaply as possible.

However, this analysis is incomplete and consequently incorrect. The problem of the durable goods monopolist is that the unconstrained solution to (1) is generally not dynamically consistent.[10] When the second period arrives, the monopolist will regard the first period as water under the bridge. It then faces the problem,

$$\max_{q_2} q_2 f_2(\delta q_1 + q_2) - C_2(q_2),$$

the solution of which implies that

(6) $$q_2 f_2' + f_2 - C_2' = 0.$$

Note how (6) compares with (3): the difference is that in the second period when the monopolist produces an extra unit it considers the effect of that unit on the price he receives for the other q_2 units sold (and thus sets $MR = q_2 f_2' + f_2 = MC = C_2'$) but does not consider the reduction in the rental value of the units previously sold but now owned by others, $\delta q_1 f_2'$. Of course, rational consumers recognize that the monopolist will not consider their interests in the second period and will adjust the price they are willing to pay for first-period purchases accordingly. Thus, with rational consumers the present value of the firm's revenue will equal the present value of the implicit rents its sales generate, so the firm still wishes to maximize (1). It must do so, however, with (6) as a constraint.[11] Maximizing (1) subject to (6), by cal-

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10. Expositions of the dynamic problem of the durable goods monopolist are provided by Coase [1972], Bulow [1982], Kahn[1982], and Stokey [1981]. Two recent papers of interest in this field are Sobel [1984] and Conlisk, Gerstner, and Sobel [1984]. Gul, Sonnenschein, and Wilson [1985] are responsible for two major advances in the field, being the first to model the dynamic monopoly problem as a formal game and providing the first general proof of Coase's original intuition.

11. Note that if the firm could rent its output instead of selling it, the monopolist could maximize the unconstrained problem. The reason is with rentals the monopolist owns all of the outstanding units and is thus able to internalize the capital loss on old units. However, in some markets rental is impractical. For example, the auto rental market faces a serious problem in monitoring the damage caused by renters and therefore cannot force renters to treat the cars as if they were their own. In some markets (e.g., computers, copiers, and shoe machinery) the government has required a dominant firm to sell instead of rent some of its output.

culating $d\pi/d\delta$ and recognizing that $dq_2/d\delta q_1$ is implicitly determined by the constraint, leads to the following condition on durability:

$$(7) \qquad \frac{1}{q_1}\frac{\partial C_1}{\partial \delta} = C_2' + \delta q_1 f_2' \frac{d(\delta q_1 + q_2)}{d\delta q_1}.$$

The intuition behind the last term in (7) is as follows: because of the constraint the monopolist suffers a loss of $\delta q_1 f_2'$ on the marginal unit it sells in the second period, relative to its precommitment in the first-period output. The term $\delta q_1 f_2'$ is simply the difference between (3) and (6). When δq_1 is increased by one unit due to increased durability, the choice of q_2 is changed by $dq_2/d\delta q_1$, which can be found by totally differentiating (6). On net, the number of units outstanding in the second period changes by $d(\delta q_1 + q_2)/d\delta q_1$, which as we will see below is usually positive. Increasing durability thus has the extra cost in this model of increasing the units on the market in the second period, and those extra units reduce profits. There is thus an incentive to reduce durability below the efficient level.

By totally differentiating (6), we find that

$$(8) \qquad \frac{d(\delta q_1 + q_2)}{d\delta q_1} = \frac{f_2' - C_2''}{2f_2' + q_2 f_2'' - C_2''},$$

which can be written as

(8')

$$\frac{d(\delta q_1 + q_2)}{d\delta q_1} = \frac{\text{slope of demand curve} - \text{slope of } MC \text{ curve}}{\text{slope of } MR \text{ curve} - \text{slope of } MC \text{ curve}}.$$

The denominator of (8') must be negative: around the optimum the slope of the marginal revenue curve must be steeper than the slope of the marginal cost curve. If the demand curve is more steeply downward sloping than the marginal cost curve, then the numerator is also negative, and (8') is positive. In this case an increase in δq_1 caused by increasing durability also increases $\delta q_1 + q_2$, and because of this effect the monopolist chooses a lower durability, or "planned obsolescence." If the marginal cost curve is steeper than the demand curve, an increase in δq_1 leads to a decrease in $(\delta q_1 + q_2)$, and the monopolist therefore chooses to produce too durable a product.[12] For the remainder of the paper we shall assume the "normal" case of the demand curve being

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12. For example, if $p_2 = \alpha - \beta\delta q_1 - \beta\delta q_2$ and $MC_2 = \gamma - (\beta + \varepsilon)q_2$, then $q_2 = (\alpha - \gamma)/(\beta - \varepsilon) - \beta/(\beta - \varepsilon)\delta q_1$, so an increase in δq_1 of one unit will *decrease*

more steeply downward sloping than the marginal cost curve, in which case the monopolist unambiguously chooses an insufficiently durable product.[13]

Thus, the monopolist will generally choose a durability below efficient levels.[14] However, in the unusual case where an increase in δq_1 will *decrease* $\delta q_1 + q_2$, which is the case when around equilibrium the marginal cost curve slopes downward more steeply than the demand curve, the monopolist will produce too durable a product.

In reality, planned obsolescence is just one of several ways in which a monopolist might mitigate the commitment problem. While there is no room for it in our finite time, full information, one-product model, firms may expend resources to establish a reputation as suggested by Kreps and Wilson [1982]. They may do so by developing a pattern for pricing a particular product over time or through pricing related products that are produced sequentially. (A publisher can gain a reputation for enforcing a substantial wait between the publication of hardcover and paperback editions, for example.) Also, a monopolist's curtailment of capacity will affect cost curves and thus be a way of committing to limit future outputs. The point of this paper is that as economists we would expect the firm to use all the means at its disposal to reduce its commitment problem, and the envelope theorem implies that a monopolist will use at least a little planned obsolescence. The two-period limitation (versus some larger finite number of shorter periods) does not alter the qualitative impli-

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q_2 by $\beta/(\beta - \varepsilon)$ and thus *decrease* $\delta q_1 + q_2$ by $\varepsilon/(\beta - \varepsilon)$. Why does this happen? Consider the experiment where δq_1 is increased by one, and we wish to discover whether q_2 is decreased by less or more than one. If δq_1 is increased by one and q_2 is decreased by exactly one, second-period marginal revenue, $q_2 f_2'(\delta q_1 + q_2) + f_2(\delta q_1 + q_2)$, changes by $-f_2'$, the negative of the slope of the demand curve. Marginal costs change by $-C_2''$, the negative of the slope of the marginal cost curve. From the initial optimum where $MR = MC$, if the marginal cost curve is steeper than the demand curve, then increasing δq_1 and decreasing q_2 by a like amount will thus leave marginal revenue below marginal costs. So, to return to $MR = MC$, q_2 will have to be decreased by more than δq_1 is increased. Therefore, if marginal costs are sharply decreasing, an increase in durability from the economically efficient level will cause a *decrease* in $\delta q_1 + q_2$ and thus cause an increase in profits.

13. This restriction on marginal costs is fairly weak. It is worth emphasizing that a firm could have considerable economies of scale in the second period (*average* costs decreasing with output) without having rapidly decreasing marginal costs.

14. There are also some tax reasons why a monopolist would prefer a less durable product. By selling a durable product, the monopolist immediately pays taxes on the present value of the future monopoly rents earned on the units sold. Further, taxes must be paid on any income earned from reinvesting those profits. With nondurable units, taxes are paid only at the time the monopolist's services are consumed.

cations of the model and often causes the results to be understated. The reason is that a considerable amount of commitment is already implied when a firm that produces in period 1 cannot produce again until half the time horizon has elapsed. With shorter periods the need to "buy" commitment via planned obsolescence and other devices can increase.

A final note concerns the welfare implications of this model. The perfectness constraint (6) reduces the monopolist's profits; that point is one of the major thrusts of the durable goods monopolist literature. But the constraint also causes inefficiencies in production, such as planned obsolescence. It is entirely possible that the constrained monopolist, while making low profits, will *reduce* discounted consumer surplus relative to an unconstrained monopolist.[15] A simple numerical example in the next footnote shows how the reduction in monopoly power *cum* planned obsolescence can be welfare reducing.[16] Thus, for example, antitrust policy requiring firms such as IBM and United Shoe to sell rather than only rent equipment may well be socially costly even as it reduces monopoly power.

The implication of small profits and large welfare losses is similar to the results of textbook monopolistic competition. Because we know that in aggregate firms' monopoly profits are relatively small,[17] results like these are important for justifying the substantial research in imperfect competition.

15. Bulow [1982, pp. 327–28] shows that a constrained monopolist may build artificially low capacity as a way of committing to a high future price, and this in itself can lead to a reduction in discounted consumer surplus relative to the unconstrained monopolist. While the point there was made in an infinite horizon model, it is easy to construct two-period examples where the same result applies: assume that a firm faces a demand curve of $p = 100 - q$ for each of two periods and the interest rate is zero. Capacity costs are $20 per unit, and one unit of capacity enables a firm to build one unit of output each period at zero marginal cost. A monopolist renter will build forty units of capacity, and produce forty in period 1 and ten in period 2. Total profits will be 4,100, and consumer's surplus will be 2,050. A monopolist seller will choose to build twenty-eight units of capacity in period 1, and produce twenty-eight units in both periods. His profits will sum to 3,920, and consumer's surplus will be 1,960. Thus, the limitation on the monopolist's power reduces both profits and consumer's surplus.

16. Assume that the inverse demand curve for rental services in each of two periods is $p = 100 - q$. The interest rate is zero. First-period units cost 20 each to build, regardless of their durability. Second-period units cost 10 to produce. A monopolist renter would build forty-five units in period 1 with maximum durability ($\delta = 1$) and rent them out each period. Producer's surplus (gross of fixed costs) would be 4,050, and consumer's surplus would be 2,025 for a total of 6,075. A monopolist seller, by contrast, would produce forty units in period 1 with a durability $\delta = \frac{1}{2}$. He would add thirty-five new units in period 2, leaving a total of fifty-five in the market in the second period. Simple arithmetic shows that total profits drop to 3,725, consumer's surplus rises to $2,312\frac{1}{2}$, and thus total surplus falls to $6,037\frac{1}{2}$.

17. See, for example, Salinger [1984].

III. The Oligopolistic Maximization Problem

This section begins by outlining an oligopolist's problem for Cournot quantity competition. The formula for durability has one extra term compared with the monopolist's formula, relating to the effect of one's durability on competitors' second-period output. With quantity competition a higher durability will usually cause competitors to cut output, and this increases one's own profitability. Therefore, there is an advantage to high durability that the oligopolist must trade off with the competing advantage of faster obsolescence.[18]

We begin by considering an oligopolist who chooses q_1 and δ in the first period and q_2 in the second period. It faces n competitors who will produce a total of $\overline{q}_1$ with a durability of $\overline{\delta}$ in the first period and will produce $\overline{q}_2(\delta q_1)$ in the second period, where $\overline{q}_2 = \Sigma_{C=1}^{n} q_2^c$ and q_2^c is the second period output of the Cth competitor. The firm's maximization problem, not much different from (1), is

$$(9) \quad \max_{q_1, \delta, q_2} q_1 f_1(q_1 + \overline{q}_1) + (\delta q_1 + q_2) f_2(\delta q_1 + \overline{\delta}\overline{q}_1 + q_2 + \overline{q}_2)$$
$$- C_1(\delta, q_1) - C_2(q_2)$$

subject to

$$f_2 + q_2 f_2' - C_2' = 0$$

and subject to

$$f_2 + q_2^c f_2' - C_2^{c'} = 0, \quad c = 1, \ldots, n,$$

where the first constraint is the perfection constraint imposed on the oligopolist, and the final n constraints recognize that in choosing δq_1 the oligopolist is also implicitly choosing his competitor's second-period outputs and that his choice in competitors' outputs is limited by the Nash requirement that each of those firms will have $MR = MC$.

Durability choice can be derived just as in the monopoly case:

$$(10) \quad \frac{1}{q_1} \frac{\partial C_1}{\partial \delta} = C_2' + \delta q_1 f_2' \frac{d(\delta q_1 + q_2)}{d \delta q_1} + (\delta q_1 + q_2) f_2' \frac{d \overline{q}_2}{d \delta q_1}.$$

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18. The first significant paper discussing the oligopoly version of this problem has just been written by Gul [1985]. Using an infinite horizon supergame framework with oligopolistic price competitors, Gul shows that there are multiple equilibria, one of which (as the length of a period to which a firm is committed to a fix price becomes small) is arbitrarily close to the monopolistic precommitment solution! Gul's paper, like most of the previous literature, assumes no depreciation.

All the terms in (10) should be familiar from the monopoly case except the last one. It states that when durability is increased so that the amount of output that lasts into the next period, δq_1, increases by one, that competitors' second-period output is changed by $d\bar{q}_2/d\delta q_1$ and this change affects the price the firm receives for the $\delta q_1 + q_2$ units of services that its output provides during the second period. If, for example, an increase in δq_1 causes competitors to reduce second-period output, then the final term in (10) will be positive and will act to increase durability, thus acting in the direction opposite from the previous term in the relation. Note that if a firm acts as a price taker, (10) shows that it chooses the efficient durability.

A sufficient condition for the last term in (10) to be positive and act to increase durability of a firm, say firm A, is that each of A's competitors' second-period marginal revenue is decreasing in industry output. Then an increase in A's durability, which has the same effect of increasing second-period industry output, will cause all competitors to contract output and thus help A's profits.[19]

IV. ILLUSTRATIONS OF THE PROBLEMS OF DURABILITY CHOICE

The analysis of Sections II and III shows that the determinants of durability choice extend beyond efficiency considerations. This section isolates these nonefficiency considerations by pro-

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19. The condition in the paragraph above can be guaranteed by two plausible assumptions. Define the total number of units on the market as $Q \equiv \delta q_1 + q_2 + \delta q_1 + \bar{q}_2$, and define the total value of implicit rents in the second period as $TR_2 \equiv Qf_2(Q)$. Then the two assumptions are first that no individual firm is producing more than $\frac{1}{2}Q$ in the second period *alone*; and second, assume that $\partial^2 TR_2/\partial Q = \partial MR_2/\partial Q < 0$, industry marginal revenue is decreasing in output. The details are left to the reader. With competition involving some strategic variable other than quantity, an oligopolist may have a strategic incentive either to increase durability (as with quantity competition) or to decrease durability. The crucial determinant is whether an increase in A's durability will raise or lower the marginal profitability of adopting a more "aggressive" second-period strategy. For example, with quantity competition A's increased durability reduces the marginal profitability of extra output and thus causes competitors to become "less aggressive" by reducing quantity. With price competition an increase in A's durability may cause competitors to charge a lower second-period price; a "more aggressive" strategy that has a negative effect on A's profits. In the language of Bulow, Geanakoplos, and Klemperer [1984], the analogy to the last term in (10) in generalized oligopolistic competition will cause A to increase durability if its competitors regard A's output as a *strategic substitute* and will cause A to decrease durability if its competitors regard A's output as a *strategic complement*. See also the excellent paper by Fudenberg and Tirole [1984].

viding illustrations of durability choice in examples where all durabilities are equal in productive efficiency.

The assumption that all durabilities are of equal efficiency in·production is of special interest for its application to how a manufacturer who could either rent or sell its outputs would choose sales as a percentage of total placements. By decreasing its sales-rental ratio, a firm is able to reduce the amount of future output services owned by customers without any loss of productive efficiency. The analogy of rental-sales strategy to durability choice is further detailed in Section V.

Both examples below involve quantity competition so that firms facing potential or actual competition will have an incentive to choose longer durabilities than a monopolist (see Section III). The first example illustrates a monopolist who expects competition in the second period. It uses durability as a way to become, effectively, a Stackelberg leader in the second period. The second example illustrates quantity competition between symmetrical firms. The optimal durability choice is derived as a function of the number of firms in the market, with the monopolist's choice of $\delta = 0$ being the result for $n = 1$.

The intuition of the examples provides the basis for a short discussion on issues of entry and collusion. Finally, the problem of a firm planning to introduce a new but related product and its strategy in choosing durability and a sales versus rental strategy is analyzed.

Example 1: The Monopolist Facing Second-Period Entry

In these examples we shall assume that firms have a constant marginal cost technology that allows them to produce units with a durability of δ at a cost of $C(1 + \delta)$. In the second period they can produce units lasting one period at a constant marginal cost of $(1 + r)C$. With this technology producing at all durabilities is equally efficient. That is, the present value of total costs is equal to $q_1C + (\delta q_1 + q_2)C$ regardless of whether the firm chooses to supply second-period demand with high durability and low q_2 or low durability and high q_2.

In this first example assume that a first-period monopolist chooses q_1 and δ. In the second period the incumbent and an entrant establish a Cournot equilibrium over the residual demand. The demand curve for rental services is $p = \alpha - \beta q_1$ in period 1 and $p = (1 + r)(\alpha - \beta \delta q_1 - \beta q_2 - \beta \bar{q}_2)$ in period 2.

Because the second-period Cournot equilibrium is $q_2 =$

$\bar{q}_2 = (\alpha - \beta\delta q_1 - C)/3\beta$, the monopolist's first-period problem can be thought of as

(11)

$$\max_{q_1,\delta} q_1(\alpha - \beta q_1 - C) + (\delta q_1 + q_2)(\alpha - \beta(\delta q_1 + q_2 + \bar{q}_2) - C)$$

subject to

$$q_2 = \bar{q}_2 = (\alpha - \beta\delta q_1 - C)/3\beta.$$

(Because of the symmetry in the position of the incumbent and the entrant in choosing second-period output, the monopolist's perfection constraint of second-period $MR = MC$ ($\alpha - \beta\delta q_1 - \beta\bar{q}_2 - 2\beta q_2 - c = 0$) and the Nash equilibrium requirement for the competitor's second-period output ($\alpha - \beta\delta q_1 - \beta q_2 - 2\beta\bar{q}_2 - c = 0$) can be simplified to the constraints above.) Solving (11) yields

$$q_1 = (\alpha - C)/2\beta, \qquad \delta q_1 = (\alpha - C)/4\beta \rightarrow \delta = \tfrac{1}{2},$$

$$q_2 = \bar{q}_2 = (\alpha - C)/4\beta.$$

So the optimum depreciation rate, if all technologies are equally efficient, is $1 - \delta = 50$ percent. Presumably if first-period technologies were differentially efficient, the monopolist would choose a durability somewhere between 50 percent and the maximally efficient level.

It is worth noting that in this problem the monopolist is able to produce the monopoly quantity in the first period and by choosing its durability achieve the Stackelberg leader position in the second period, where $\delta q_1 + q_2 = (\alpha - C)/2\beta$ and $\bar{q}_2 = (\alpha - C)/4\beta$.[20] This is a simple illustration of the tradeoffs in durability where increased durability implies a lower second-period price but a bigger market share for the incumbent.

Example 2: Symmetric Oligopoly

Using the same setup as in Example 1, we solve for the symmetric perfect Cournot-Nash equilibrium in a game with n firms producing in each of two periods. We look at the problem of a firm choosing q_1 and δ in the first period and q_2 in the second, knowing that its $(n - 1)$ competitors will each produce $\bar{q}_1$ units with a

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20. This Stackelberg result can be derived under reasonably general conditions.

durability of $\bar{\delta}$ in period 1 and that a Cournot-Nash equilibrium will be established on residual demand in the second period. The firm's problem is to

(12)

$$\max_{q_1, \delta} q_1(\alpha - \beta q_1 - \beta(n-1)\bar{q}_1 - C) + (\delta q_1 + q_2)(\alpha - \beta(\delta q_1$$
$$+ \delta(n-1)\bar{q}_1 + q_2 + (n-1)\bar{q}_2) - C)$$

subject to

$$q_2 = \bar{q}_2 = (\alpha - \beta(\delta q_1 + (n-1)\delta \bar{q}_1) - C)/\beta(n+1),$$

where the constraint is again implied by the second-period equilibrium. As with (11) symmetry enables us to combine the firm's perfection constraints on its own output with the constraints that it is limited in its implicit choice of competitor's second-period output to their meeting the Nash equilibrium conditions. It is easy to solve (12) for a symmetrical equilibrium:

$$q_1 = \bar{q}_1 = \frac{\alpha - C}{\beta(n+1)}, \qquad \delta q_1 = \bar{\delta}\bar{q}_1 = \frac{(\alpha - C)(n-1)}{\beta(n^2+1)},$$

$$q_2 = \bar{q}_2 = \frac{\alpha - C}{\beta(n^2+1)}, \qquad \delta = \frac{n^2-1}{n^2+1}.$$

For a monopolist ($n = 1$) the optimal value of δ is zero: there is a disadvantage to durability in that it causes low future prices; there is no corresponding advantage to a monopolist in causing competitors to cut back on future output.[21] In this example $\delta = 0.6$ for a duopoly and approaches 1 as n increases. While oligopolists do have a durability tradeoff, this result does *not* imply that with technologies of differential efficiency that more and more firms in the industry will lead to more and more excessive durability. As more firms enter, profit margins decrease, and firms cannot afford to stray so far from efficient production techniques.

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21. Note that the optimal value for a monopolist's δ is zero; the firm would not choose a *negative* δ even if possible. What, economically, is a negative depreciation rate? Barry Nalebuff suggests that it has a role in a model of addiction: for given δ, the more units sold in the first period, the *greater* the demand in the second period. If our friendly monopolist were selling heroin, then it would prefer that the product be neither satiating nor nonaddictive: intuitively, those who do buy in the first period will be "hooked" and pay a big second-period price for the product, but this will not compensate for the customers who never try the product because of its addictive quality.

Entry Deterrence and Collusion

Inspection of the examples also provides intuition about issues of entry deterrence and oligopolistic collusion. Increasing durability reduces the demand for new units and thus reduces the profitability of all firms including a new entrant in period 2. In Example 1, the monopolist might choose a durability in excess of 0.5 if there are fixed costs of entry and the increased durability will prevent entry.[22]

Example 2 can be used to show the advantage to oligopolists of colluding on the durability of their products. It is easy to ascertain that the higher the durability of period 1 output, the lower the equilibrium price in period 2. In this example if firms were constrained to choosing a lower level of durability in period 1, they would end up (weakly) increasing q_1 relative to what they would choose at the Nash durability and reducing $\delta q_1 + q_2$. For example, in a collusive agreement to set $\delta = 0$, the firms would all set $q_1 = q_2 = (\alpha - C)/(n + 1)\beta$ and earn Cournot-Nash profits for each of two periods. Formally, the maximization problem becomes the same as (12) with the added constraint that $\delta = \delta^c$, the collusive δ.[23] In the example, industry profits are increased, the lower the collusive durability. Intuitively, without collusion firms choose increased durability up to the point where the total derivative of their own profits with respect to durability is zero. But at this point incremental durability, effectively increasing firms' second-period quantity, reduces competitors' profits. So if it is possible to collude on the rate of obsolescence but not on price, firms will be able to increase industry profits by reducing durability from noncooperative levels.

If an oligopoly such as the American automobile industry were colluding on durability, then, it would likely be in the direction of planned obsolescence. The entry of foreign competitors to make the industry more competitive would then move durability toward efficient levels.

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22. If the fixed costs also must be paid by the monopolist for operating in the second period, the monopolist may even be better off. A high enough durability may effectively permit the monopolist to precommit to not producing in period 2, raising the price received in period 1 and the present value of discounted profits.

23. Let $X \equiv [(n + 1)^2 + \delta(n - 1)]/[(n + 1)^3 + \delta^2(n^2 + 1)]$. Then if δ is fixed, each firm in Example 2 would choose $q_1 = X(\alpha - C)/\beta$ and $q_2 = (1 - n\delta X)(\alpha - C)/\beta(n + 1)$. Industry profits over the two periods will be $\Pi_1 + \Pi_2 = (\alpha - c)^2/\beta(nX(1 - nX) + n/(n + 1)^2(1 + \delta X)(1 - n\delta X))$ which turns out to be decreasing in δ over the range $0 \leqslant \delta \leqslant 1$.

V. Sales versus Rentals

Finally, we consider how a firm that has the choice between selling and renting its output should balance its placements. Again a simple modification of the two illustrative examples is of use. Assume that all units produced in the first period last two periods and cost $2C$ to produce. Units built in the second period last one period and cost $(1 + r)C$ to produce. The firms must choose first-period outputs, and decide what fraction of those units should be sold and what fraction rented. Then firms will choose q_1 just as in the examples and choose a sales percentage just as they chose δ in the original examples.[24] That is, in Example 1 the monopolist will sell half its output and rent half. In Example 2, each oligopolist will sell $(n^2 - 1)/(n^2 + 1)$ of its first-period output. The reason for the close analogy between a rental-sales ratio and a depreciation rate is that when a firm sells δ units with a life of two periods and rents $(1 - \delta)$ units, it essentially selling one unit of output for the current period and δ units for the following period, just as if it sold a depreciating asset. The sole difference is that the production and rental of durables gives a firm marginal costs of zero in the second period until all of the first-period rentals are disposed of. Because examples 1 and 2 give firms constant marginal costs and firms always distribute more units in period 2 than they rented in period 1, this difference does not affect the equilibrium in those examples.[25]

The analogy of rental-sales strategies to durability enables one to make predictions about the evolution of a firm's rental-sales ratio as the degree of competition it faces changes. A mo-

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24. This exact equivalence would not hold in other examples where the equilibrium number of units on the market in the second period would be less than the number in the first period, for example because second-period demand was weaker than first-period demand.

25. More formally, assume that $\partial^2 C_1/\partial q_1^2 = \partial^2 C_2/\partial q_2^2 = 0$ so that marginal costs are constant each period and

$$\frac{1}{q_1} \frac{\partial C_2}{\partial \delta} = \frac{\partial C_2}{\partial q_2}$$

so that there are no economies or diseconomies associated with a change in durability choice. Then the costs in the oligopolistic maximization problem (9), $C_1(\delta,q_1) + C_2(q_2)$, can be rewritten as $C(q_1,\delta q_1 + q_2)$. In that case the maximization problem is precisely the same for a firm that faces an exogenous δ and chooses a sales-rental ratio and one that can choose δ but can only sell, as long as we have an interior solution (no units are rented in the first period and left idle in the second). The general interpretation of δ would be the fraction of first-period placements that are both serviceable in the second period and owned by customers.

nopolist has an incentive to rent, proving to customers that it will not reduce prices too much in the future. By contrast, a firm that either faces or will shortly face some competitors in its current product line or some closely related new products will also have a contrasting incentive to sell. The sales, like greater durability, free the firm to place more new units in the future and may thus improve the firm's competitive position. Additionally, the smaller a firm's market share the more elastic its demand for any given market elasticity. With price less sensitive to any given percentage change in the firm's quantity, there is less incentive to rent rather than sell to commit to low quantity.

To check the prediction that as a dominant firm encounters more competition it will increase its sales-rental ratio, I gathered all publicly available data on the breakdown of revenues between sales and rentals for both IBM and Xerox. As Table I shows, both firms have substantially increased their sales-rental ratios since 1970.

Unfortunately, there are at least five caveats that reduce the

TABLE I

BREAKDOWN OF REVENUES, 1966–1983

| | IBM | | | Xerox | | |
	Sales	Percentage Rentals	Services	Sales	Percentage Rentals	Services
1983	57.9	23.0	19.1	45.9	39.1	15.1
1982	48.9	32.4	18.7	41.2	47.0	11.8
1981	44.4	37.3	18.3	40.1	51.0	8.9
1980	41.7	41.5	16.9	37.9		62.1
1979	41.4	44.0	14.5	34.2		65.8
1978	41.5	46.4	12.1	31.3		68.7
1977	39.1	60.9		26.9		73.1
1976	36.6	63.4		22.8		77.2
1975	31.5	68.5		20.0		80.0
1974	33.8	66.2		20.1		79.9
1973	30.7	69.3		19.1		80.9
1972	30.2	69.8		20.1		79.9
1971	26.4	73.6		20.3		79.7
1970	27.0	73.0		21.8		78.2
1969	35.8	64.2		26.2		73.8
1968	41.8	58.2		21.8		78.2
1967	35.0	65.0		N.A.		N.A.
1966	31.6	68.4		N.A.		N.A.

N.A. = not available.
Source. 10-K Reports filed by IBM and Xerox with Securities and Exchange Commission, various years.

value of this evidence in confirming the theory. First, and perhaps most important, conventional price discrimination theory has argued that sometimes a rental contract will enable a monopolist to-meter consumers and charge more to heavy users. There is thus an identification problem in distinguishing the price discrimination and durable goods theories of sales versus rentals.

Second, while Xerox's market share has declined dramatically since 1970, and it is clearly facing stiffer competition, the situation with IBM is much less clear. IBM's old line competitors such as Burroughs, Univac, NCR, Control Data, and Honeywell do not seem to have made great strides in recent years. On the other hand, the plug compatible manufacturers who provide the closest substitutes for IBM products have grown dramatically in the past decade. Therefore, it is not easy to say whether IBM faces stiffer competition now than it did in the past.[26]

Third, neither sales nor rental contracts may be as simple as in this model. For example, long-term binding rental agreements are economically similar to sales, whereas sales contracts that give the purchaser the right to sell back the machine to the manufacturer may be economically like rental contracts. Therefore, the financial form of placement contracts may have deceiving implications about economic substance.[27]

Fourth, the firms' product mixes have changed since 1970, and some new products, such as personal computers for IBM, may lend themselves more readily to sales rather than rentals.

Fifth, 1981 changes in United States tax law have decreased the tax incentive for manufacturer leasing. The tax advantage to such leasing can be summarized by the following example: suppose that IBM builds a computer at a cost of $600,000 and can either sell it for $1 million to a competitive leasing firm or else lease it to customers directly. If all parties are in the same tax bracket, the tax cost of IBM selling the asset rather than leasing it is the tax on an immediate $400,000 profit, less the incremental investment tax credit and the present value of the incremental depreciation deductions created by the asset having a tax basis of $1 million instead of $600,000. Under the Accelerated Cost Recovery System (ACRS) the present value of depreciation de-

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26. Fisher et al. [1983] argue that IBM does face stiffer competition than in the past. They also argue that it had virtually no monopoly power even in the early part of my sample period.

27. That many purchasers may be leasing companies who rent equipment is *not* a problem, however. For the purposes of this paper's analysis, so long as the monopolist itself does not maintain a direct interest in the market value of a machine after its initial placement, the placement qualifies as a sale.

ductions has been dramatically increased to the point where the tax advantage to manufacturer leasing has been virtually eliminated. This change in the tax laws has probably affected firms' sales-rental policies.[28]

Nevertheless, analysis in the business press has argued that IBM's recent policy of increasing sales versus rentals has been implemented because of competitive considerations. The IBM Credit Corp. was established two years ago to facilitate its customers' outright purchase of machinery, altering the company's historical policy of encouraging customers to lease rather than buy its machines. As a result the fraction of company revenues derived from rentals has dropped by over a third in two years.[29] "More important, the trend to customers' purchasing more of their equipment frees the company to introduce machines more frequently—a lethal competitive edge."[30]

VI. CONCLUSION

Monopolists generally have an incentive to produce goods with inefficiently short useful lives. There are only minor exceptions to this rule. The reason for this rule derives from the perfection constraint of the durable goods monopolist, which forces him in the long run to charge lower prices than would an unconstrained firm. By reducing the durability of its output, the monopolist can reduce the cost of its perfection constraint.

An oligopolist, or a monopolist facing future entry, has the same considerations as the monopolist plus the extra consideration of how its durability will effect competitors' future strategies. If the firm faces Cournot-Nash competition, it will usually find that increased durability will reduce competitors' future output. Since a reduction in competitors' output will, all else equal, raise a firm's profits, such oligopolists have a countervailing incentive to increase durability and may choose either excessively long or short lives for their products.

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28. For a lucid summary of these issues see Miller and Upton [1976]. Of course, the 1981 tax law also created incentives for some firms, most notably Boeing, to lease rather than sell. The reason is that when equipment such as an airliner was transferred abroad but used partially in the United States, the 1981 law allowed the lessor a 10 percent investment tax credit and an accelerated depreciation writeoff. See Merry [1983]. This tax advantage has since been eliminated.

29. See Table I.

30. See Andrew Popper, "How the IBM Juggernaut Will Keep Rolling," *Business Week*, July 16, 1984, p. 106.

If a firm wishes to deter entry into its markets, then it will prefer longer durabilities, or equivalently it will have a preference to sell rather than rent more of its output. On the other hand, if oligopolists can collude to set the durability of the industry's products, they will opt for some planned obsolescence. Antitrust policy that requires durable goods monopolists to sell rather than rent their products will reduce their profitability but may also reduce welfare. Thus, while such policies reduce monopoly power, they will not necessarily add to efficiency.

The movements of IBM and Xerox to a greater reliance on sales rather than rentals as they have encountered greater competition are loosely consistent with some of the predictions of this theory.

Perhaps the greatest weakness of this paper is that it follows in the tradition of using durability as a proxy for obsolescence. This assumption, combined with the perfect second-hand market assumption, permits the model to regard goods produced at different times as homogeneous, and greatly simplifies the analysis. But 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. In a market such as textbooks, the publishers' inability to internalize the capital losses suffered by holders of used books seems to lead to excessive efforts to make succeeding editions of a book incompatible with one another; this result seems consistent with our theory.[31] But in other markets, such as that for personal computers, customers may value their purchases more highly the *greater* their expectations of future sales. Such markets are not well accommodated by the model presented here. However, modeling such markets will necessarily require abandonment of the perfect second-hand market assumption, because with perfect second-hand markets and downward sloping demand curves first-period purchasers must necessarily lose by increased second-period sales. The inability of customers to resell will introduce considerations akin to those of conventional price discrimination into the analysis. This complication, combined with the difficulty in allowing for product differentia-

31. John Kaplan tells the story of one of his Stanford law students asking if he could get by with the previous edition of Kaplan's textbook in his course. The author responded to the student, "If an intelligent person is revising his textbook, do you think he's going to redo it in such a way that you can use the old version?"

tion in an enlightening way, means that further advances in this field will necessarily require models that are more complex than this one.

These issues mean that planned obsolescence is still a difficult and poorly understood topic. It is my hope, however, that the simple analysis of this paper and its emphasis on the sequential nature of this problem will help provide the basic intuition for approaching future research in this area.

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