Firm Behavior and Product Durability

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Traditional models of product obsolescence assume firms exhibit specific behavior. The simple two period model developed herein employs a conjectural variation framework to examine the sensitivity of sub-optimal durability within sales markets to behavioral assumptions. Even in sales markets, this model leads to two cases where efficient durability occurs and two cases where inefficient durability occurs. (*JEL* Classification: L15)

I. Introduction

The popular press often asserts imperfectly competitive firms pursue product obsolescence strategies.[1] Economists, however, differ on whether market structure affects product durability and consequently on whether planned obsolescence pays. For example, Swan (1970) finds market structure does not affect product durability under constant returns to scale. Saving (1982) also finds no relation between product reliability and market structure. Implicitly, the results of Swan and Saving apply to rental markets (cf. Goering 1992a, b). However,

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[1]For example, a recent computer industry analyst (Seymour 1991, p. 73) urged Intel, a sole source supplier of microprocessors, to "... aggressively make its products obsolete." As a further example, the *New York Times* recently published an article on the gun industry which illustrates the thinking behind planned obsolescence strategies (Eckholm 1992, p. 1+). "But for Mr. Ruger, a legendary gun designer who is proud of his products, part of the solution to market overload is 'planned obsolescence.' The article further quotes Ruger, "'We've woken up to the fact that these guns are not wearing out, and used guns are competing with our new production, ...'"

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Bulow (1982, 1986) argues imperfectly competitive firms will choose socially sub-optimal durability (planned obsolescence) for output sold as opposed to output rented to customers, due to commitment problems implied by the Coase conjecture (1972). Intuitively, durable products sold to customers act as potential substitutes to the firm's future production and thus the firm may limit this competition through planned obsolescence. French (1988), however, has shown that contingent installment contracts can reduce planned obsolescence even in sales markets.

This paper generalizes the results from the previously cited durability models to demonstrate product durability and quality depend upon the form of conjectures and the choice variable employed.[2] Surprisingly, the literature has devoted little attention to these facets of equilibrium durability. In a more general setting, firm behavior can lead to (a) inefficient durability as in Bulow; or (b) socially optimal quality and durability as in Saving or Swan. We show (a) occurs when firms collude on output or have Cournot conjectures. We show (b) occurs when firms compete on price or have consistent conjectures. Even in sales markets these different equilibria may occur, which suggests product durability may vary independently of market structure. Thus, firm behavior plays a pivotal role and can overpower pure market structure effects. The conjectural variation model of durability choice appears in Section II, Section III presents four cases of interest, while Section IV summarizes the key results.

II. A Conjectural Variations Model of Durability Choice

This section examines the effects conjectures have upon product durability. As in Bulow (1986), we analyze a two-period discrete time model. Let the subscripts i and j denote different firms within the industry of N firms ($i, j = 1 \ldots N$ where $i \neq j$). Furthermore, to concentrate on the oligopolistic market structure, assume $N > 1$. Let q_{1i} and q_{2i} denote the i'th firm's output in periods one and two. In the first period firms also choose a durability D_i, representing the fraction of period one production remaining in period two service. Hence, a unit of first period output with durability D_i can be sold at $P_1 + \beta D_i P_2$. Assume $P_t = a - bQ_t$ specifies the demand for each period's services where

[2]See Goering and Pace (1994) for a 500 word abstract of these results.

$$Q_1 = \sum_{j=1}^{N} q_{1j} \quad \text{and} \quad Q_2 = \sum_{j=1}^{N} (D_j q_{1j} + q_{2j}) \tag{1}$$

Q_1 and Q_2 represent the total stock of industry output in periods one and two. For simplicity, assume constant returns to scale with respect to output. Let $c(D_i)$ and $c(0)$ represent the marginal production costs for firm i in periods one and two. Naturally, products manufactured in the second period should have zero durability given the simple two-period framework. Accordingly, $c'(D_i) > 0$, $c''(D_i) > 0$, and $c(0) > 0$.

Solving for the subgame perfect equilibria requires analyzing the game (firms' maximization problems) in reverse order. If the firm has sold its first period output, its second period profit function is

$$\Pi_{2i} = \{a - bQ_2 - c(0)\}q_{2i}. \tag{2}$$

The maximization of (2) with respect to the choice variable q_{2i} yields (3).

$$\frac{\partial \Pi_{2i}}{\partial q_{2i}} = a - bQ_2 - bq_{2i}\left(\frac{\partial Q_2}{\partial q_{2i}}\right) - c(0) = 0. \tag{3}$$

In (3) the term within brackets represents firm i's beliefs or expectations concerning the sensitivity of the industry stock to its period two production changes. Combining (1) and (3) yields

$$\frac{\partial Q_2}{\partial q_{2i}} = 1 + \sum_{j \neq i} \frac{\partial q_{2j}}{\partial q_{2i}}. \tag{4}$$

The i'th firm's conjectural variation, $\partial q_{2j}/\partial q_{2i}$, represents the perceived sensitivity of firm j's second period production level to the i'th firm's period two output decision.

Rational consumers and firms recognize the Nash equilibrium condition in (3) determines the firms' second period outputs. Hence, (3) constrains the firm's first period behavior. Let β represent a discount factor accounting for the opportunity cost of money over time. The i'th firm maximizes (5) by its choice of q_{1i} and D_i subject to (3).

$$\Pi_i = \{a - bQ_1 - c(D_i)\}q_{1i} + \beta\{(a - bQ_2)(D_i q_{1i} + q_{2i}) - c(0)q_{2i}\}. \tag{5}$$

For simplicity assume constant, symmetric conjectural variations. Hence, in equilibrium all firms share a common conjectural variation ($\upsilon = \partial q_{2j}/\partial q_{2i}$). The maximization of (5) subject to (3) with respect to durability (ignoring firm subscripts) produces (6).[3]

[3]See Appendix B for the complete derivation of (6).

$$\frac{\partial \Pi}{\partial D} = q_1(\beta c(0) - c'(D) + \delta) = 0, \tag{6}$$

where $\delta = \dfrac{\beta b\{1 + (N-1)\upsilon\}}{N + 1 + (N-1)\upsilon}\{(N-1)(1+\upsilon)q_2 - Dq_1\}.$

As examination of (6) reveals, the exact conjectural variation crucially affects the firm's optimal durability choice.[4] In general, the durability chosen differs from the socially optimal, perfectly competitive level as defined by

$$\beta c(0) - c'(D) = 0. \tag{7}$$

Taking (6) and (7) together implies the socially optimum level of durability occurs when $\delta = 0$.

This socially optimal durability depends solely upon cost-minimization and not upon production levels given constant returns to scale. In equation (6) the added term δ combines the strategic effect (represented by $(N-1)(1+\upsilon)q_2$) stemming from the negative relation between durability and rivals' second period outputs and the planned obsolescence effect (represented by $-Dq_1$) stemming from the firm's commitment problem with consumers.

In the case of monopoly, the strategic effect vanishes leaving only the planned obsolescence effect. Hence, this model produces the standard result as a special case. In the case of oligopoly, insofar as these effects oppose each other, δ may assume a positive or negative value. If general, durability depends upon the number of firms (market structure) and differs indeterminately from the socially efficient level. However, (6) suggests δ may also equal zero and hence efficient durability may prevail in sales markets in certain cases. Consequently, this model encompasses the results of Swan, Saving, and Bulow as special cases. The following section presents two cases where firm behavior results in efficient durability and two cases where it may not.

III. Durability Cases within Sales Markets

This section examines the equilibria in sales markets in four different cases. The first case examines the effect of using price as a choice vari-

[4]Obviously, firms could also form conjectures concerning rival durability choice. In common with the existing literature, we assume a zero value for these "durability conjectures" in the derivation of (6).

able. The second case examines the effect of consistent conjectures. The third case examines the effect of Cournot conjectures. The fourth case examines the effect of collusion. A discussion concludes the section.

A. Choice Variable Case

An equilibrium involving a particular choice variable, such as output, often changes upon substitution of another choice variable, such as price. This suggests the type of choice variable may affect product durability in equilibrium. For example, as Bulow (1986, p. 738) states, "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." As this quote illustrates, the consequences of changing to price as a choice variable do not seem obvious *a priori*.

Typically, durability models of this kind assume output remaining from previous periods perfectly substitutes for current output. Hence, in any period the price depends upon the total stock of output regardless of its time of origin. In addition, these models generally assume technology exhibits constant returns to scale. Consequently, with perfectly substitutable (perfectly homogeneous) goods and constant returns to scale (constant marginal cost with respect to output) Bertrand price competition may ensue with firms choosing price instead of output. As in static non-durable goods models, the output conjecture of $v = -1/(N-1)$ has a Bertrand interpretation. Substituting this conjecture into (6) yields $\delta = 0$ and thus firms choose efficient durability as defined by (7). As (6) and the definition of δ suggest, durability will attain the efficient level when firms use price as the choice variable. Intuitively, in a price setting game, firms will have an incentive to undercut each other in the final period (period two). Consequently, price in period two will equal marginal manufacturing cost. Since price equals marginal cost in period two, firms have no incentive to deviate from efficient (cost-minimizing) durability in period one (see Appendix A for a proof). Hence, using price as a choice variable does not result in a strategic interest to increase or decrease durability from the efficient level. Thus, this case yields results identical to those of Swan and Saving.

B. Consistent Conjectures Case

What constitutes a reasonable conjecture? Rationality or consistency of conjectures appears to offer one criteria, albeit controversial, for determining "reasonable" conjectures. Rational or consistent firms correctly conjecture concerning their rivals' behavior (at least locally). In this model, consistent conjectures means the expected change in the rivals' output levels equals the actual change. While the term consistency emerged from the works of Bresnahan (1981) and others, this intuitive concept actually originated much earlier (Leontief 1936) as a natural response to the concepts of Stackelberg (1934) (see Pace and Gilley 1990).

As Kamien and Schwartz (1983) show, $\upsilon = -1/(N-1)$ constitutes a consistent conjecture under constant marginal production cost. Substituting this conjecture into (6) yields (7), the perfect competition condition. Intuitively, as in the preceding case, the consistent conjecture $\upsilon = -1/(N-1)$ results in a period two equilibrium where price equals marginal cost. Thus, the firms have no incentive to deviate from the cost-minimizing durability. Consequently, firms with consistent conjectures choose the socially optimal durability.

C. Cournot Case

If we follow the standard, previously cited durability models and assume Cournot behavior ($\upsilon = 0$), equation (6) reduces to (8).

$$\delta = \left(\frac{\beta b}{N+1}\right)\{(N-1)q_2 - Dq_1\}. \tag{8}$$

Hence, durability only attains the socially efficient level by accident when firms have Cournot conjectures on output. Specifically, for socially efficient durability, $\delta = 0$ and thus $(N-1)q_2 = Dq_1$ must hold. In this case, the strategic effect which induces firms to increase durability exactly offsets the planned obsolescence effect which induces firms to decrease durability. *A priori*, the strategic and planned obsolescence effects will typically not offset each other. Therefore, a Cournot equilibrium in output can result in greater or lesser durability than the social optimum.

D. Collusive Case

If identical firms collude on output perfectly but not on durability choice, $\upsilon = 1$ in (6). Such a case could arise if firms find it easier to observe rivals' output than durability. Substituting this into (6) produces (9).[5]

$$\delta = \frac{\beta b}{2}\{2(N - 1)q_2 - Dq_1\}. \tag{9}$$

As in the Cournot case, δ will not necessarily equal 0. No economic rationale exists for why the strategic and planned obsolescence effects would tend to exactly offset each other. Hence, oligopolists who collude on output will not tend to produce the socially effective cost-minimizing durability.

E. Discussion

In the consistent conjectures and choice variable cases the equilibrium conjectures ($v = -1/(N - 1)$) results in the independence of the firm's durability choice from the market structure (N). Even in sales markets, consistent conjectures or price competition leads to the independence of durability choice and market structure. Hence, the presence of a relatively small number of firms does not guarantee planned obsolescence—this result must stem from the firms' behavior. This theoretical result also agrees with the empirical findings of Avinger (1981). Although Avinger found empirical support for planned obsolescence in several industries (e.g., electric lamps, vacuum tubes), he argued firms' behavior towards each other dominated market structure effects, such as the number of firms in the industry.

The Cournot and collusive cases also document the importance of firms' behavior as the important determinant of equilibrium relative to pure market structure (number of firms). Indeed, if the strategic effect is strong enough ($\delta > 0$), the Cournot and collusive cases suggest firms could manufacture products exceeding the social efficient level of durability.

IV. Conclusion

Standard durability models assume specific behavior among firms and typically conclude firms will engage in planned obsolescence if output is sold. This paper generalizes these models and finds the type of conjectural variations or choice variable firms employ fundamentally affects product durability in sales markets. Naturally, under many con-

[5]The strategic durability effect still exists since, by assumption, firms do not collude on durability choice.

ditions it may pay for firms to engage in planned obsolescence. This position has some empirical support (e.g., Avinger) and may very well prevail in many industries.

Conversely, the analysis herein showed either an equilibrium characterized by consistent conjectures or by price competition results in firms manufacturing products exhibiting socially optimal durability and quality. Moreover, this result persists across a range of market structures. Indeed, one can find casual empirical support for these theoretical results in the U.S. sporting gun industry, an industry characterized by a relatively few producers with rising concentration. As previously mentioned, the gun industry has experimented over its history with product obsolescence strategies. Nevertheless, we observe (1) firms manufacturing highly durable products; and (2) firms exiting the industry due to losses—a result consistent with Bertrand competition. The model herein accounts for both of these effects.

Whether firms engage in planned obsolescence depends upon firm behavior within the industry and not upon market structure *per se* as often proxied for by the number of firms. As the important special cases of price competition or consistent conjectures illustrate, products of optimal quality and durability can emerge from within any market structure. The potential for these special cases may help explain the variation in planned obsolescence across industries.

In fact, other aspects of firm behavior could create additional variation in planned obsolescence across industries. For example, allowing each firm to conjecture concerning rival durability choice would greatly complicate the relationships among market structure, the presence of a sales or rental markets, and durability choice. Insofar as the simple two-period model developed herein yielded the complete range of possible outcomes, the addition of such durability conjectures would not change the fundamental insight concerning the indeterminacy of planned obsolescence with respect to market structure. Nevertheless, this and the other assumptions discussed previously illustrate the need for further investigation into the behavior underlying durability and quality choice.

Appendix A—Price as Choice Variable

This appendix demonstrates that a selling firm's durability choice is efficient (cost-minimizing) when price is used as a choice variable. Suppose that the demand for the ith firm's output in period t is given by

$$\text{Case 1: } q_{ti} = 0 \qquad \text{if } P_{ti} > P_{tj} \text{ for any } j \neq i$$

$$\text{Case 2: } q_{ti} = \frac{1}{n+1}\left(\frac{a - P_{ti}}{b} - X_t\right) \qquad \begin{array}{l}\text{if there exists no } P_{ti} < P_{tj} \\ \text{for any } j \neq i \text{ and } n \geq 1 \\ \text{is the number of firms} \\ \text{such that } P_{ti} = P_{tj} \text{ for all } j \neq i.\end{array} \tag{A1}$$

$$\text{Case 3: } q_{ti} = \frac{a - P_{ti}}{b} - X_t \qquad \text{if } P_{ti} < P_{tj} \text{ for any } j \neq i,$$

where X_t is the amount of output which remains in service from previous periods at time t, ($X_1 = 0$ and $X_2 = \sum_{j=1}^{N} D_j q_{1j}$). The demand equation specified in (A1) is the standard form used when the goods are perfectly homogeneous, modified to account for the durable nature of the product. It indicates that firm i's quantity demanded in any period can broken into 3 cases: (1) if a rival offers a lower price, firm i's quantity demanded falls to zero; (2) if it is not undercut but charges a price equal to n other firms, it shares the market equally; (3) if it charges the lowest price, it can sell to the entire market. If the firms maximize their profits given the price other firms charge, an equilibrium where $\Pi_t > 0$ is not possible since it provides an incentive for firms to undercut each other given the above demand specification in (A1). Thus, assuming positive production in period two, the standard Bertrand price cutting behavior will hold and price will be bid down to constant marginal cost $c(0)$. If the price in the second period is equal to marginal cost ($P_2 = c(0)$) in equilibrium, the firms have no incentive to deviate from the cost-minimizing durability level (either for strategic or commitment purposes). Hence, if the firms use price as their decision variable instead of output levels, their product durability will be socially optimal and independent of market structure (N) as long as $N > 1$.

Appendix B—Derivation of Equation 6

Plugging in the symmetric constant conjecture v into (3) yields,

$$a - bQ_2 - bq_{2j}\{1 + v(N-1)\} - c = 0 \tag{B1}$$

where for expositional ease c represents $c(0)$. Summing for all j yields,

$$N(a - c) - NbQ_2 - b\{1 + v(N-1)\}\sum_j q_{2j} = 0 \tag{B2}$$

Aggregating the second period output and the first period output which has survived into the second period defines the period two stock in (B3).

$$Q_2 = \sum_j D_j q_{1j} + \sum_j q_{2j} \tag{B3}$$

Substituting (B3) into (B2) yields (B4).

$$N(a-c) - Nb\sum_j D_j q_{1j} - Nb\sum_j q_{2j} - b\{1+\upsilon(N-1)\}\sum_j q_{2j} = 0 \tag{B4}$$

Rearranging (B4) produces (B5)

$$N(a-c) - Nb\sum_j D_j q_{1j} = \{N+1+\upsilon(N-1)\}b\sum_j q_{2j} \tag{B5}$$

Furthermore, rearranging (B5) yields (B6).

$$\sum_j q_{2j} = \frac{N(a-c)}{b\{N+1+\upsilon(N-1)\}} - \frac{N}{\{N+1+\upsilon(N-1)\}}\sum_j D_j q_{1j} \tag{B6}$$

Simplifying (B6) yields (B7).

$$\sum_j q_{2j} = \frac{N}{\{N+1+\upsilon(N-1)\}}\left\{\frac{(a-c)}{b} - \sum_j D_j q_{1j}\right\} \tag{B7}$$

Substituting (B7) into (B1) given (B3) and solving for q_{2i} yields (B8).

$$q_{2i} = \frac{(a-c)}{b\{1+\upsilon(N-1)\}} - \frac{\sum_j D_j q_{1j} - \sum_j q_{2j}}{\{1+\upsilon(N-1)\}} \tag{B8}$$

Substituting (B7) again into (B8) yields (B9).

$$\begin{aligned} q_{2i} = {} & \frac{(a-c)}{b\{1+\upsilon(N-1)\}} - \frac{\sum_j D_j q_{1j}}{\{1+\upsilon(N-1)\}} \\ & - \frac{N}{\{N+1+\upsilon(N-1)\}\{1+\upsilon(N-1)\}}\left\{\frac{(a-c)}{b} - \sum_j D_j q_{1j}\right\} \end{aligned} \tag{B9}$$

Collecting terms and simplifying yields (B10).

$$q_{2i} = \frac{1}{\{1+\upsilon(N-1)\}}\left[\frac{(a-c)}{b} - \sum_j D_j q_{1j}\right. \tag{B10}$$

$$- \frac{N}{\{N+1+\upsilon(N-1)\}}\left\{\frac{(a-c)}{b} - \sum_i D_j q_{1j}\right\}\Bigg]$$

Further simplification produces (B11).

$$q_{2i} = \frac{1}{\{1+\upsilon(N-1)\}}\left[\frac{1+\upsilon(N-1)}{\{N+1+\upsilon(N-1)\}}\left\{\frac{(a-c)}{b} - \sum_j D_j q_{1j}\right\}\right] \tag{B11}$$

Rewriting (B11) yields (B12).

$$q_{2i} = \left[\frac{1}{\{N+1+\upsilon(N-1)\}}\left\{\frac{(a-c)}{b} - \sum_j D_j q_{1j}\right\}\right] \quad \forall i \tag{B12}$$

Taking the partial derivative of the *i*th firm's period two output with respect to durability yields (B13).

$$\frac{\partial q_{2j}}{\partial D_i} = -\frac{q_{ij}}{N+1+(N-1)\upsilon} \quad \forall i, j \tag{B13}$$

Aggregating the second period output and the first period output which has survived into the second period defines the period two stock.

$$Q_2 = \sum_i D_i q_{1i} + \left[\frac{N}{\{N+1+\upsilon(N-1)\}}\left\{\frac{(a-c)}{b} - \sum_i D_i q_{1i}\right\}\right] \tag{B14}$$

Using (B13) leads to (B15).

$$\frac{\partial Q_2}{\partial D_i} = q_{1i} - \frac{N q_{1i}}{N+1+\upsilon(N-1)} \tag{B15}$$

Simplifying yields (B16).

$$\frac{\partial Q_2}{\partial D_i} = \left\{\frac{1+\upsilon(N-1)}{N+1+\upsilon(N-1)}\right\} q_{1i} \tag{B16}$$

Differentiating the firm's profit function with respect to durability leads to the following first order condition (B17).

$$\begin{aligned} \frac{\partial \pi_i}{\partial D_i} &= -c'(D_i) q_{1i} \\ &+\beta\left\{(D_i q_{1i} + q_{2i})\left(-b\frac{\partial Q_2}{\partial D_i}\right) + (a - bQ_2)\left(q_{1i} + \frac{\partial q_2}{\partial D_i}\right) - c\frac{\partial q_2}{\partial D_i}\right\} = 0 \end{aligned} \tag{B17}$$

Note, $(a - bQ_2) = c + b\{1 + (N-1)v\}q_{2i}$ from (B1). Substituting into (B17) yields (B18).

$$\frac{\partial \pi_i}{\partial D_i} = -c'(D_i)q_{1i} + \left[\beta c q_{1i} + \beta[b\{1 + (N-1)v\}q_{2i}]\left(q_{1i} + \frac{\partial q_2}{\partial D_i}\right)\right. \\ \left. - \beta(D_i q_{1i} + q_{2i})\left(b\frac{\partial Q_2}{\partial D_i}\right)\right] = 0 \tag{B18}$$

Substituting (B13) and (B15) into (B18) produces (B19).

$$\frac{\partial \pi_i}{\partial D_i} = -c'(D_i)q_{1i} + \beta c q_{1i} + \delta q_{1i} = 0 \tag{B19}$$

The following are some equivalent forms for δ.

$$\delta = \beta b\{1 + (N-1)v\}q_{2i}\left\{1 - \frac{1}{N + 1 + (N-1)v}\right\} \\ - \beta b(D_i q_{1i} + q_{2i})\left\{\frac{1 + (N-1)v}{N + 1 + (N-1)v}\right\}$$

$$\delta = \left[\frac{\beta b\{1 + (N-1)v\}q_{2i}\{N + (N-1)v\}}{N + 1 + (N-1)v}\right] - \left[\frac{\beta b(D_i q_{1i} + q_{2i})\{1 + (N-1)v\}}{N + 1 + (N-1)v}\right]$$

$$\delta = \left[\frac{\beta b\{1 + (N-1)v\}}{N + 1 + (N-1)v}\right]\left[\{N + (N-1)v - 1\}q_{2i} - D_i q_{1i}\right]$$

$$\delta = \left[\frac{\beta b\{1 + (N-1)v\}}{N + 1 + (N-1)v}\right]\left\{(N-1)(1+v)q_{2i} - D_i q_{1i}\right\}$$

This last expression matches equation (6) in the text.

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