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Product Durability in Markets with Consumer Lock-in

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Abstract

This paper examines a two-period duopoly where consumers are locked-in by switching costs that they face in the second period. The paper's main focus is on the question of how the consumer lock-in affects the firms' choice of product durability. We show that firms may face a prisoners' dilemma situation in that they simultaneously choose non-durable products although they would have higher profits by producing durables. From a social welfare perspective, firms may even choose an inefficiently high level of product durability.

Journal of Economic Literature Classification Numbers: *L13, D21*
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1 Introduction

The relation between market structure and product durability has been on the economists' research agenda for a long time. The existing literature, however, does not take into account the impact of consumer lock-in on firms' durability choice. In many markets, consumers face costs of switching from a product to one of its substitutes. For example, users of hardware products such as computers, hand-held organizers or digital-music players learn how to use their brand and invest in appropriate software. These costs may be sunk when changing the brand.[1] Examples show that product durability is an important issue for hardware firms. Shorter warranty periods indicate that hardware firms tend to reduce the lifetime of their products. For example, in 2001, Dell Computer reduced warranty periods from three years to one. Apple Computer's iPod digital audio player comes with only a 90-day warranty and Sony requires purchasers to register to get a full year of support on a Clie organizer - otherwise, they, too, get 90 days of warranty.[2]

These examples raise the question of why firms would want to reduce durability. We will show in a two-period duopoly framework that firms may face a prisoners' dilemma situation in that they simultaneously choose non-durable products in the initial stage although they would be better off by producing durables. The explanation is as follows: Consumer lock-in gives firms monopoly power over their market segments in the second period. Since second-period profits increase with first-period market shares, firms compete more aggressively in the first period. In our model, the first-period competition more than dissipates firms' extra monopolistic returns of the second period so that consumer lock-in reduces firms' overall profits. By jointly choosing durable products (i.e. products that last for two periods), firms could overcome the negative competition effect of consumer lock-in and would realize the same overall profits as in the case without consumer lock-in. However, in some cases, the joint choice of durable products cannot be implemented in equilibrium. If the marginal costs of producing durables are relatively large compared to the marginal costs of non-durable products, each firm has the incentive to unilaterally deviate (i.e. to choose non-durable

[1] See Klemperer (1995) for further categories of switching costs.

[2] Source: http://www.stayfreemagazine.org/public/wsj-planned-obsolescence.html

products). Whenever firms choose the same level of durability, costs can be completely shifted to consumers. However, if firms choose different levels of durability, overall profits depend on marginal costs. Thus, each firm could take advantage of the large difference in costs by deviating.

Furthermore, the examples of reduced warranty periods raise the question of market efficiency. A standard result of the existing literature on product durability is that firms choose excessive obsolescence, i.e. products have an inefficiently low lifetime.[3] We will show that the equilibrium where both firms choose non-durable products is harmful to firms but efficient from a social welfare perspective. In this sense, the equilibrium with non-durable products cannot be characterized as "excessive obsolescence". Moreover, we will challenge the perspective of "excessive obsolescence" by showing that both firms may even choose an inefficiently high level of durability if differences in marginal costs (with respect to durability) are low. In this situation, firms jointly choose durable products in equilibrium. Since firms do not internalize costs that they can shift to consumers, they provide an excessive level of durability.

The result that consumer lock-in may lead to excessive durability is a novel contribution to the literature on product durability. In a fundamentally different approach, Fishman et al. (1993) show that a competitive market may generate too much durability in equilibrium. They consider an economy with overlapping generations of consumers and a large number of firms. In each period, a randomly chosen firm has the opportunity to develop a new technology but innovation is costly. In return for the innovation, the innovator firm would gain a temporary monopoly position. The potential innovator's incentive to develop a new technology is reduced when the old consumer generation holds durable products, i.e. the temporary monopoly position would be less attractive. Eventually, due to economies of scale in the production of durability, firms may repeatedly produce durables, which in turn impede firms' incentives to innovate. For certain development costs, innovation may be desirable from a social welfare perspective, whereas the scale economy associated with durability would lead to technological stagnation.

[3] See, for example, Waldman (1993), Choi (1994) and Grout and Park (2005) for work on the issue of "excessive obsolescence".

Moreover, our paper is related to a second strand of literature dealing with switching costs and consumer lock-in. Klemperer (1987) considers a two-period duopoly model with intertemporally changing consumer preferences. In the first period, rational consumers anticipate that they will be partially locked in to their first-period supplier due to switching costs. When making their first-period purchase decisions, consumers predict the second-period prices which depend on the first-period market shares. Rational consumers anticipate that a first-period price cut that increases the firm's first-period market share would result in a higher second-period price. Thus, rational expectations with respect to the second-period prices make consumers first-period demand less elastic than it would be in an identical market without switching cost. Eventually, switching costs may either increase or reduce firms' overall profits. Our model follows Klemperer (1987) in considering a spatial location duopoly model of product differentiation. The main differences between our model and Klemperer's are: (i) We extend the model by assuming that products may either last for one or for two periods so that we can analyze the firms' durability choice. (ii) For the sake of tractability, we confine our analysis to the case where all second-period consumers were in the first-period market and have unchanged preferences.[4] In our model, switching costs clearly reduce the firms' overall profits. By jointly choosing durable products, firms may mitigate the effects of switching costs. Alternatively, as shown by Farrell and Gallini (1988), firms may license their product to second-source suppliers thereby committing themselves to lower prices in the future. In return, their products become more attractive at the present time. Farrell and Shapiro (1989) consider the case where firms may write long-term contracts to reduce their market power over locked-in consumers.

The remainder of this paper is organized as follows. The next section sets up the model structure. In Section 3, we analyze the second-period equilibrium that depends on the first-period market shares. Section 4 deals with first-period pricing depending on the initially chosen levels of product durability. In Section 5, we endogenize the firms' durability choice and we discuss its welfare implications. Section 6 contains concluding remarks. The proofs of formal results are relegated to an appendix.

[4]Klemperer (1987) briefly discusses the second-period equilibrium for this case.

2 The Model Setup

We consider a two-period market where two firms offer differentiated products. In the initial stage, both firms $i = A, B$ simultaneously choose the level of product durability $d^i \in \{1, 2\}$. A *non-durable* good ($d^i = 1$) lasts for one period and a *durable* good ($d^i = 2$) lasts for two periods. Firms have unit costs increasing with the level of durability but no fixed costs. Let $c_{II} > c_I$, where c_I stands for the unit costs of $d^i = 1$ and c_{II} denotes the unit costs of $d^i = 2$. In addition, we assume that each firm can produce at costs c_I a product with one-period durability in the second (and last) period.

In the first period, firms A and B simultaneously set prices p_1^A and p_1^B to maximize their total discounted profits. A spatial location model of horizontal product differentiation is used to describe preferences: Consumers are uniformly arrayed along the interval $[0, L]$ and firm A and B located at 0 and L, respectively. Thus a consumer at $z \in [0, L]$ incurs a transport cost z of using product A or $(L - z)$ of using B's product. Whereas consumers face different transport costs, they have identical reservation prices r. Assume that each consumer will only buy from one firm in any period and that it is not possible to store products between periods.

In the second period consumers have the same tastes for the underlying product characteristics as in the first period, i.e. unchanged transport costs. If consumers have purchased a non-durable product in the first period, they have to repeat purchase in the second period. A crucial assumption is that consumers face switching costs s of buying a product that they have not previously bought.[5]

For simplicity, we make the following three assumptions with respect to the parameters. In particular, these assumptions confine the model to the case

[5]As Klemperer (1987) or Padilla (1992), we do not explicitly model start-up costs which consumers incur in the first period. Generally, start-up costs are similar to the new investment (switching cost) that a brand switcher must make. Since these costs are unavoidable for consumers, they would not alter our analysis, as long as consumers' participation constraints are fulfilled. Suppose that $L = c_I = \delta = 1$, $r = 4$, $s = 3$ and $1 < c_{II} < 2$ holds. For this example, all participation constraints are fulfilled, even if consumers must pay a start-up costs $s = 3$, and the same results as in section 5 can be derived.

where all consumers buy in the first and in the second period (if there is a need to repeat purchase). Detailed explanations are postponed to Sections 3 and 4. In Section 5, we consider a numerical example that satisfies Assumptions 1-3.

Assumption 1 $2L + c_I \leq r \leq c_I + s$

Assumption 1 defines sufficient conditions for a second-period Nash equilibrium. As Section 3 will explain in detail, the left-hand side of this assumption guarantees that each firm sells to all its previous consumers in the second period. The right-hand side states that switching costs must be sufficiently large to give firms monopoly power over their locked-in consumers. As Proposition 2 will show, Assumption 1 is also sufficient to guarantee for the symmetric case with $d^A = d^B = 1$ that all consumers buy in the first period.

Assumption 2 $c_{II} \leq \hat{c_{II}} = (1+\delta)(2r - 3L)/2$

As we will show in Propositions 3 and 4, Assumption 2 ensures for the symmetric case with $d^A = d^B = 2$ and for the asymmetric case ($d^i = 1$ and $d^{j \neq i} = 2$) that the first-period market is covered.

Assumption 3 $\alpha < c_{II} < \beta$, *where*

$$\begin{aligned} \alpha &:= (1+\delta)c_I - L(3+2\delta), \\ \beta &:= (1+\delta)(3L + c_I). \end{aligned}$$

In the asymmetric case ($d^i = 1$ and $d^{j \neq i} = 2$), large differences in costs c_I and c_{II} may result in the monopolization of the first-period market. Assumption 3 guarantees that both firms sell in the first period, i.e. $\sigma^{i*} \in (0,1)$. For simplicity, we confine our analysis to this case.

The time structure of the model is summarized in Figure 1: First firms simultaneously choose durability (d^A, d^B). In the subsequent stage firms simultaneously set first-period prices (p_1^A, p_1^B) where each firm observes the durability choice of the competitor. Then, consumers make their first-period purchase decision for given prices (p_1^A, p_1^B). Finally, firms simultaneously set second-period prices (p_2^A, p_2^B). If consumers have bought a non-durable product in the first period, they have to repeat purchase in the second period.

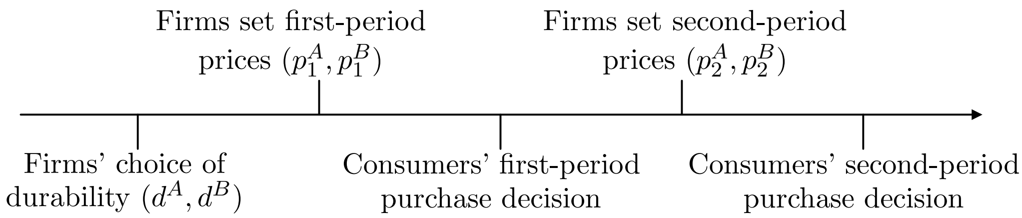

Figure 1: The Sequence of Events

3 The Second Period

In this section, we derive the firms' profit-maximizing second-period prices as functions of the first-period market shares σ^i. For simplicity, we assume that all consumers have bought in the first period. The second-period prices depend on the firms' durability choice in the initial stage. Suppose that firm i has chosen durability $d^i = 1$ in the initial stage. Then, consumers who have previously bought product i have to repeat purchase in the second period. Proposition 1 specifies the equilibrium strategies. Recall that Assumption 1 defines sufficient conditions for a second-period Nash equilibrium.

Proposition 1 *Suppose that all consumers have bought in the first period. The profit-maximizing prices of firm $i = A, B$ depend on the firm's initially chosen level of durability d^i and on its first-period market share σ^i:*

(i) If $d^i = 1$, firm i's profit-maximizing second-period price is given by $p_2^{i*} = r - \sigma^i L$ and second-period profits are equal to $\Pi_2^{i*} = (r - \sigma^i L - c_I)\sigma^i L$.

(ii) If $d^i = 2$, firm i can set any price $p_2^{i*} \geq c_I$ and second-period profits are equal to $\Pi_2^{i*} = 0$.

These price strategies constitute the second-period Nash equilibrium for any market share $0 < \sigma^i < 1$ if Assumption 1 holds.

Proof: see Appendix.

Part (i) of Proposition 1 refers to to the case of $d^i = 1$ and states that firm i acts as a monopolist on its base of previous consumers. The most distant first-period buyer of product i incurs transport costs $\sigma^i L$ of using product i again. Then, firm i may completely extract the second-period surplus of this most distant buyer by setting the second-period price equal to $p_2^{i*} = r - \sigma^i L$. Alternatively, firm i could choose a higher price thereby abandoning some of its locked-in consumers. The left-hand side of Assumption 1 ($2L + c_I \leq r$) makes this strategy unprofitable. Thus, if consumers' reservation price r is large enough compared to L and to marginal costs c_I, firm i sells to all its previous consumers in the second period (Proof: see Appendix).

The right-hand side of Assumption 1 ($r \leq c_I + s$) states that switching costs must be sufficiently large to give firm i monopoly power over its segment of locked-in consumers. To see the intuition behind this assumption, consider the most distant consumer of the B segment who incurs transport costs $\sigma^B L$ of using product B. If this consumer buys product B again, his surplus is completely extracted by $p_2^{B*} = r - \sigma^B L$. He would prefer product A to B if $r - \sigma^A L - p_2^A - s > 0$. Thus, with prices $\hat{p}_2^A < r - \sigma^A L - s$, firm A could attract previous buyers of product B. Notice that the condition $r < c_I + s$ is sufficiently strict to ensure that the undercutting price $\hat{p}_2^A = r - \sigma^A L - s - \epsilon$ is always below marginal costs c_I , i.e. even if $\sigma^A \to 0$ firm A would incur a loss by intruding into the rival firm's segment. Also, this implies for the asymmetric case ($d^i = 1$ and $d^{j \neq i} = 2$) that firm j could not compete for second-period buyers who have previously bought product i. Therefore, firm j could set any price $p_2^{j*} \geq c_I$ without selling products in the second period, as stated in part (ii) of Proposition 1.

Proposition 1 shows that second-period prices p_2^{i*} decrease with market share because the surplus of the most distant consumer is reduced by larger transport costs. However, σ^i has a positive effect on second-period profits, i.e. $\partial \Pi_2^{i*} / \partial \sigma^i > 0$. Thus the negative price effect is offset by the positive effect on demand.

4 The First Period

The first-period prices depend on the durability levels firms have chosen in the initial stage. In the following analysis, we distinguish three cases: The symmetric case with low durability ($d^A = d^B = 1$), the symmetric case with high durability ($d^A = d^B = 2$) and the asymmetric case where $d^i = 1$ and $d^{j \neq i} = 2$. The second-period profits, as stated in Proposition 1, can be used in the first-period maximization problem because they are defined for any market share.

4.1 Symmetric Case with Low Durability

We first start with the symmetric case where both firms have chosen non-durable products ($d^A = d^B = 1$) in the initial stage. Consider a first-period consumer located at z. The consumer's overall surplus from buying product A is

$$r - z - p_1^A + \delta[r - z - (r - \sigma^{Ae} L)]. \tag{1}$$

In the first period, the consumer gets reservation utility r but he incurs transport cost z of using product A. In addition, he must pay the first-period price p_1^A. The expression in the square brackets refers to the consumer's second-period surplus in the case he buys product A again where δ denotes the discount factor.[6] Again, the consumer gets r and incurs transport cost z. Moreover, he anticipates the second-period price $p_2^A = r - \sigma^{Ae} L$ which depends on the expected first-period market share σ^{Ae} of firm A. Analogously, the consumer's overall surplus from buying product B in both periods is equal to

$$r - (L - z) - p_1^B + \delta[r - (L - z) - (r - \sigma^{Be} L)]. \tag{2}$$

The marginal consumer is indifferent between buying product A and B, so that

$$z = \frac{L + 2\delta\sigma^{Ae} L - p_1^A + p_1^B}{2(1 + \delta)}. \tag{3}$$

As in Klemperer (1987), we set $\sigma^{Ae} = \sigma^A = z/L$, so that expectations are fulfilled. Then, firm A's market share is equal to

$$\sigma^{Ae} = \sigma^A = \frac{L - p_1^A + p_1^B}{2L}. \tag{4}$$

[6] As stated in Assumption 1, switching costs s are sufficiently large to ensure that each firm has monopoly power over its segment of locked-in consumers. Thus, we can ignore the case that the consumer switches to the competitor's product in the second period.

Firms' $(i = A, B)$ overall profits are given by

$$\Pi^i = (p_1^i - c_I)\sigma^i L + \delta(r - \sigma^i L - c_I)\sigma^i L. \tag{5}$$

Both firms simultaneously set prices, thereby taking into account the impact of first-period market shares on the second-period prices. Proposition 2 states the first-period equilibrium prices and overall profits.

Proposition 2 *Consider the case where both firms have chosen $d^A = d^B = 1$ in the initial stage. Suppose that Assumption 1 holds, which is sufficient to ensure that all consumers buy in the first period. Then, the symmetric first-period equilibrium prices are given by*

$$p_1(1,1)^* = (L + c_I)(1 + \delta) - \delta r$$

and overall profits are equal to

$$\Pi(1,1)^* = \frac{L^2(2+\delta)}{4}.$$

Proof: see Appendix.

Under Assumption 1, first-period prices are lower than they would be if there were no second period (i.e. $\delta = 0$). This standard result of the switching cost literature can be explained as follows: Since second-period profits increase with market share, firms compete more aggressively in the first period. Also, first-period prices decrease with r because high reservation prices raise second-period profits, thereby making the competition for market share more fierce.[7] The reservation price r has no impact on overall profits. Thus, the positive effect on second-period profits is completely compensated by the negative effect on the first-period profits. Due to symmetry, firms can completely shift the costs to consumers as long as c_I is not too high compared to r. As Proposition 2 states, Assumption 1 guarantees that all consumers buy in the first period (Proof: see appendix).

[7] It may be worthwhile for firms to subsidize consumers in the first period's competition for market share which is the prerequisite for second-period profits.

4.2 Symmetric Case with High Durability

We now analyze the symmetric case where both firms have chosen $d^A = d^B = 2$ in the initial stage. Consider a first-period consumer located at z. The consumer's overall surplus from buying product A is

$$(1+\delta)(r-z) - p_1^A. \tag{6}$$

In both periods, the consumer gets reservation utility r minus transport costs z of using product A. Since product A is durable, the consumer does not need to repeat purchase in the second period. Analogously, the consumer's overall surplus from buying product B is equal to

$$(1+\delta)[r-(L-z)] - p_1^B \tag{7}$$

The marginal consumer is indifferent between buying product A and B, so that

$$\sigma^A = \frac{L(1+\delta) - p_1^A + p_1^B}{2L(1+\delta)}. \tag{8}$$

Since firms ($i = A, B$) do not sell products in the second period, profits are simply given by

$$\Pi^i = (p_1^i - c_{II})\sigma^i L. \tag{9}$$

Recall that Assumption 2 ensures for the case $d^A = d^B = 2$ that all consumers buy in the first period. Proposition 3 specifies the first-period equilibrium prices and the overall profits.

Proposition 3 *Consider the case where both firms have chosen $d^A = d^B = 2$ in the initial stage. All consumers buy in the first period if (and only if) Assumption 2 holds. Then, the symmetric first-period equilibrium prices are given by*

$$p_1(2,2)^* = L(1+\delta) + c_{II}$$

and overall profits are equal to

$$\Pi(2,2)^* = \frac{L^2(1+\delta)}{2}.$$

Proof: see Appendix

4.3 Asymmetric Case

Finally, consider the case where $d^A = 1$ and $d^B = 2$. Then, a first-period consumer located at z will buy product A if $r - z - p_1^A + \delta[r - z - (r - \sigma^{Ae}L)]$ is greater than $(1+\delta)[r - (L - z)] - p_1^B$. The marginal consumer is indifferent between buying product A and B, so that

$$z = \frac{L(1+\delta) - p_1^A + p_1^B - \delta(r - \sigma^{Ae}L)}{2(1+\delta)}. \tag{10}$$

Expectations must be fulfilled, so that $\sigma^{Ae} = \sigma^A = z/L$. Then, the market share is equal to

$$\sigma^{Ae} = \sigma^A = \frac{L(1+\delta) - \delta r - p_1^A + p_1^B}{L(2+\delta)} \tag{11}$$

Firms' profits are given by

$$\begin{aligned} \Pi^A &= (p_1^A - c_I)\sigma^A L + \delta(r - \sigma^A L - c_I)\sigma^A L \quad , \\ \Pi^B &= (p_1^B - c_{II})(1 - \sigma^A)L. \end{aligned} \tag{12}$$

The following Proposition states the first-period equilibrium prices and overall profits.

Proposition 4 *Consider the case where where $d^A = 1$ and $d^B = 2$. Suppose that Assumptions 1-3 hold. Then, all consumers buy in the first period and first-period equilibrium prices are given by*

$$\begin{aligned} p_1^A(1,2)^* &= \frac{(3L + 2\delta L + c_{II})(2 + 3\delta) + 2c_I(1+\delta)(2+\delta)}{6 + 5\delta} - \delta r, \\ p_1^B(1,2)^* &= \frac{(1+\delta)[(3L + c_I)(2+\delta) + 4c_{II}]}{6 + 5\delta} \end{aligned}$$

Firm A's equilibrium market share $\sigma^{A*} \in (0,1)$ is equal to

$$\sigma^A(1,2)^* = \frac{c_{II} - \alpha}{L(6 + 5\delta)}$$

Finally, overall profits are given by

$$\Pi^A(1,2)^* = \frac{2(1+\delta)(c_{II}-\alpha)^2}{(6+5\delta)^2} \quad ,$$
$$\Pi^B(1,2)^* = \frac{(2+\delta)(\beta-c_{II})^2}{(6+5\delta)^2}.$$

Proof: see Appendix

In Proposition 4, Assumption 1 guarantees that the second-period profits, as stated in Proposition 1, can be used in the first-period maximization problem. Assumption 2 ensures for the symmetric case ($d^A = d^B = 2$) that all consumers buy in the first period. We show in the appendix that this assumption is also sufficient to guarantee for the asymmetric case ($d^i = 1$ and $d^{j \neq i} = 2$) that the first-period market is covered. Assumption 3 confines the analysis to interior solutions, i.e. $\sigma^{i*} \in (0,1)$. In Section 5, we consider a numerical example that satisfies Assumptions 1-3.

Unlike in the symmetric cases, equilibrium prices and profits depend on marginal costs c_I and c_{II}. Moreover, $p_1^A(1,2)^*$ decreases with r. This is the same effect as in the case of $p_1(1,1)^*$ and can be explained analogously: High reservation prices increase the second-period profits of firm A. This makes firm A more aggressive in the first-period competition for market share. However, firm A's equilibrium profits $\Pi^A(1,2)^*$ do not depend on r. Thus, as in the first symmetric case, the positive effect on second-period prices is completely compensated by the negative effect on first-period profits. Under Assumption 3, equilibrium profits depend on exogenous variables in the usual way, i.e. the profits of both firms increase with L and δ, firm A's profits decrease with c_I and increase with c_{II}, and firm B's profits increase with c_I and decrease with c_{II}.

5 Initial Stage: Durability Choice

In this section, we endogenize the firms' durability choice and we discuss its welfare implications.

5.1 Equilibrium Choice of Durability

We first start with the firms' equilibrium choice of durability. In the initial stage, firms simultaneously choose the level of product durability $d_i \in \{1, 2\}$, thereby anticipating overall profits Π^{i*} that depend on the durability choice of both firms. The profits are depicted in the following matrix.

	$d^B = 1$	$d^B = 2$
$d^A = 1$	$\frac{L^2(2+\delta)}{4}, \frac{L^2(2+\delta)}{4}$	$\frac{2(1+\delta)(c_{II}-\alpha)^2}{(6+5\delta)^2}, \frac{(2+\delta)(\beta-c_{II})^2}{(6+5\delta)^2}$
$d^A = 2$	$\frac{(2+\delta)(\beta-c_{II})^2}{(6+5\delta)^2}, \frac{2(1+\delta)(c_{II}-\alpha)^2}{(6+5\delta)^2}$	$\frac{L^2(1+\delta)}{2}, \frac{L^2(1+\delta)}{2}$

Matrix 1: Overall Profits and Durability

It is important to note that $\Pi(2,2)^*$ is always greater than $\Pi(1,1)^*$. Recall that switching costs give firms monopoly power over their market segments in the second-period. This effect leads to vigorous competition for market share in the first period. In our model, the vigorous first-period competition more than dissipates firms' extra monopolistic returns of the second period. By jointly choosing $d^i = 2$, firms can overcome this negative competition effect. However, it depends on the profits in the asymmetric case of whether $d^A = d^B = 2$ constitutes a Nash equilibrium or not. The following Proposition specifies the equilibrium choice of durability.

Proposition 5 *Suppose that Assumptions 1 - 3 hold. Then, the first-stage decisions of the firms in the subgame perfect equilibrium of the overall game are as follows:*

(i) If $c_{II} > \delta L/2 + (1+\delta)c_I$, the durability choice $d^A = d^B = 1$ constitute the unique equilibrium.

(ii) If $c_{II} < \delta L/2 + (1+\delta)c_I$, the durability choice $d^A = d^B = 2$ constitute the unique equilibrium.

Proof: see Appendix.

Consider the case where $r = 4$ and $L = \delta = 1$. For this example, Figure 2 illustrates the equilibria depending on c_I and c_{II}. Assumption 1 restricts costs to $c_I < \bar{c_I} = r - 2L = 2$. As stated in Assumption 2, $c_{II} < \hat{c_{II}} = (1+\delta)(2r-3L)/2 = 5$. In this numerical example, Assumption 3 is satisfied as long as Assumptions 1 - 2 hold. Recall that $c_{II} > c_I$, as stated in Section 1, so that points below the $c_{II} = c_I$-line should be ignored. In region A, c_{II} is relatively large compared to c_I and $d^A = d^B = 1$ constitutes the unique equilibrium because $c_{II} > \delta L/2 + (1+\delta)c_I = 1/2 + 2c_I$. On the other hand, region $B + C$ depicts values of c_I and c_{II} where $d^A = d^B = 2$ is the unique equilibrium.

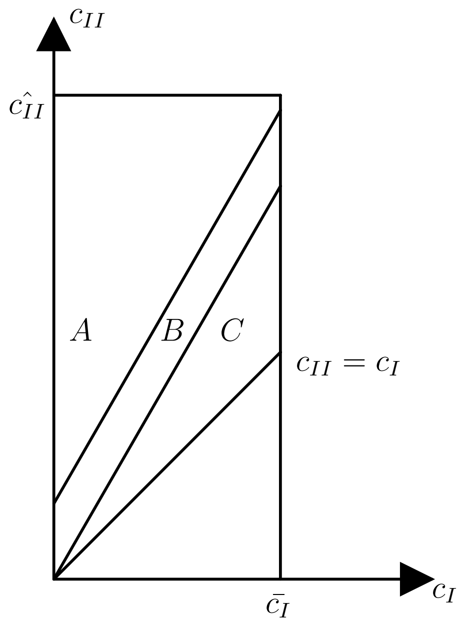

Figure 2: Equilibrium Choice of Durability

In region A, firms face a prisoners' dilemma situation: Since $\Pi(2,2)^*$ is always greater than $\Pi(1,1)^*$, both firms would gain from the cooperative outcome $d^A = d^B = 2$. However, given the cooperative outcome, each firm would defect because $\Pi^A(1,2)^* = \Pi^B(2,1)^* > \Pi(2,2)^*$. Why would firms gain from defection? In region A, marginal costs c_{II} are relatively large compared to c_I. As already shown, costs have no impact on firms' profits in the symmetric cases because they can be completely shifted to consumers.[8] However, in the asymmetric case, equilibrium profits depend on marginal costs as shown in Proposition 4. In region A, it is worthwhile to defect (i.e. to choose $d^i = 1$) and thus taking advantage of the large difference in costs.

Analyzing the comparative statics, we find that region A expands compared to region $B + C$ if market size L and discount factor δ decrease. This implies that the prisoners' dilemma outcome ($d^A = d^B = 1$) would also occur for relatively low values of c_{II}.

5.2 Socially Efficient Choice of Durability

After having derived the firms' equilibrium choice of durability, we analyze the welfare implications. The following Proposition states the socially efficient levels of durability, as chosen by a social planner who maximizes the sum of overall profits ($\Pi^A + \Pi^B$) and of overall consumer surplus ($CS^A + CS^B$) with respect to d^A and d^B where CS^i denotes the overall surplus of the product i buyers. In the symmetric cases, prices are nothing but monetary transfers between consumers and firms that have no impact on social welfare.

Proposition 6 *Suppose a social planner maximizes $W = \sum_i \Pi^i(d^A, d^B) + \sum_i CS^i(d^A, d^B)$ with respect to d^A and d^B.*

(i) If $c_{II} \leq (1 + \delta)c_I$, social welfare is maximized by the durability choice $d^A = d^B = 2$.

(ii) If $c_{II} \geq (1 + \delta)c_I$, social welfare is maximized by the durability choice $d^A = d^B = 1$.

Proof: see Appendix.

Proposition 6 shows that the socially efficient durability choice depends only on differences in costs and on the discount factor. The production of durable products is efficient if the costs c_{II} are lower than the total costs of producing non-durable products which are equal to $(1 + \delta)c_I$. If firm i

[8] Recall that Assumptions 1 - 3 ensure that all consumers buy.

chooses $d^i = 1$, it incurs costs c_I in each period, where the second-period costs are discounted. The asymmetric case is always inefficient because total costs are not minimized and consumers' transport costs are higher than in the symmetric cases where $\sigma^i = 1/2$.

Figure 2 illustrates the welfare implications of the firms' durability choice. In region $A + B$, the durability choice $d^A = d^B = 1$ is socially efficient because $c_{II} > (1 + \delta)c_I = 2c_I$. On the other, $d^A = d^B = 2$ would maximize social welfare in region C. Comparing the equilibria with the socially efficient outcomes, we find that firms choose an inefficiently high level of durability in region B. From a social welfare perspective, firms should choose $d^A = d^B = 1$ because c_{II} is relatively large compared to c_I. However in region B, firms can realize the cooperative outcome $d^A = d^B = 2$ in equilibrium. It is not worthwhile to defect as the differences in costs are not large enough from the firms' profit perspective. Needless to say that firms do no internalize costs that they can shift to consumers. In region C, the differences in costs are so small that a social planner would choose $d^A = d^B = 2$ as well.

6 Conclusion

In addition to the existing literature on product durability, this paper studies the impact consumer lock-in may have on firms' durability choice. We first show that firms may face a prisoners' dilemma situation in that they simultaneously choose non-durable products although they would have higher profits by producing durables. As in some classical models with switching costs, consumer lock-in reduces firms' overall profits because firms' extra monopolistic returns of the second period are more than dissipated by first-period competition. By the joint choice of durable products, firms could mitigate the negative competition effect of consumer lock-in. However, if the marginal costs of producing durables are relatively large compared to the marginal costs of non-durable products, each firm has the incentive to unilaterally deviate to non-durable products. Whenever firms choose the same level of durability, costs can be completely shifted to consumers as long as consumers' reservation price is sufficiently large. However, if firms choose different levels of durability, overall profits depend on marginal costs. Thus, each firm could take advantage of the large difference in costs by deviating.

In contrast to the common result of "excessive obsolescence", we show that both firms may even choose an inefficiently high level of durability if differences in marginal costs (with respect to durability) are low. In this situation, firms jointly choose durable products in equilibrium. Since firms do not internalize costs that they can shift to consumers, they provide an excessive level of durability.

Appendix

Proof of Proposition 1: Consider the case where both firms have chosen $d^i = 1$ in the initial stage. We will show, without loss of generality, that firm A does not gain from a single deviation from the equilibrium price $p_2^{A*} = r - \sigma^A L$. If firm A deviated by choosing a higher price $\tilde{p}_2^A > p_2^{A*}$, its second-period sales, $\tilde{z}_2^A = r - \tilde{p}_2^A$, would be lower than its first-period sales $\sigma^A L$. Thus, firm A would abandon some of its locked-in consumers and thereby realizing profits

$$\tilde{\Pi}_2^A = (\tilde{p}_2^A - c_I)(r - \tilde{p}_2^A) \tag{13}$$

Substitution of $\tilde{p}_2^A = r - \sigma^A L + \epsilon$ into the first derivative of (13) yields

$$\frac{\partial \tilde{\Pi}_2^A}{\partial p_2^A} = 2L\sigma^A + c_I - r - 2\epsilon \tag{14}$$

Expression (14) must be negative for any market share $0 < \sigma^A < 1$. Substitution of $\epsilon \to 0$ and $\sigma^A \to 1$ into (14) yields

$$\frac{\partial \tilde{\Pi}_2^A}{\partial p_2^A} = 2L + c_I - r < 0 \quad \Leftrightarrow \quad r > 2L + c_I \tag{15}$$

Thus, firm A will not exceed the equilibrium price because for any price greater than $p_2^{A*} = r - \sigma^A L$, profits decrease with prices. On the other hand, firm i has no incentive to undercut the rival firm because the undercutting price $\hat{p}_2^A = r - \sigma^i L - s - \epsilon$ is always below marginal costs as long as $r < c_I + s$ holds. Q.E.D.

Proof of Proposition 2: Consider the case where firms have chosen $d^A = d^B = 1$ in the initial stage. Substitution of equation (4) into (5) and maximization with respect to p_1^A yields the following first-order condition:

$$\frac{\partial \Pi^A}{\partial p_1^A} = \frac{(1+\delta)(L + c_I) - \delta(p_1^A - p_1^B + r) - 2p_1^A + p_1^B}{2} = 0 \tag{16}$$

In the symmetric equilibrium we get

$$p_1^{A*} = p_1^{B*} = (L + c_I)(1 + \delta) - \delta r. \tag{17}$$

In Proposition 2 we have claimed that Assumption 1 is sufficient to ensure that all consumers buy in the first period. It remains to be verified if the first-period market is actually covered. The marginal consumer anticipates that firm A will completely extract his surplus in the second period, i.e. $r - L/2 - p_2^{A*} = 0$. He will buy if (and only if) his first-period surplus is at least equal to zero:

$$r - \frac{L}{2} - p_1^{A*} \geq 0 \quad \Leftrightarrow \quad r \geq \frac{L}{2(1+\delta)} + L + c_I. \tag{18}$$

Since $2L + c_I > L/[2(1+\delta)] + L + c_I$, this constraint always holds under Assumption 1. Q.E.D.

Proof of Proposition 3: Suppose that firms have chosen $d^A = d^B = 2$ in the initial stage. Substitution of equation (8) into (9) and maximization with respect to p_1^A yields the following first-order condition:

$$\frac{\partial \Pi^A}{\partial p_1^A} = \frac{L(1+\delta) + c_{II} - 2p_1^A + p_1^B}{2(1+\delta} = 0 \tag{19}$$

In the symmetric equilibrium we get

$$p_1^{A*} = p_1^{B*} = L(1+\delta) + c_{II}. \tag{20}$$

As in the previous case, it must be ensured that all consumers buy in the first period. The marginal consumer buys if (and only if)

$$(1+\delta)\left(r - \frac{L}{2}\right) - p_1^{A*} \geq 0 \Leftrightarrow c_{II} \leq \hat{c_{II}} = \frac{(1+\delta)(2r - 3L)}{2}. \tag{21}$$

This is equivalent to Assumption 2. Q.E.D.

Proof of Proposition 4: Suppose that firms have chosen $d^A = 1$ and $d^B = 2$ in the initial stage. Substitution of equation (11) into (12) and maximization with respect to p_1^A and p_1^B yields the following first-order conditions:

$$\begin{aligned} \frac{\partial \Pi^A}{\partial p_1^A} &= \frac{(1+\delta)[L(2+3\delta)+c_I(2+\delta)]-4\delta^2 r}{(2+\delta)^2} \\ &+ \frac{\delta(3p_1^B-4p_1^A-4r)-2(2p_1^A-p_1^B)}{(2+\delta)^2}=0 \qquad (22) \\ \frac{\partial \Pi^B}{\partial p_1^B} &= \frac{L+c_{II}+\delta r+p_1^A-2p_1^B}{2+\delta}=0 \qquad (23) \end{aligned}$$

Solving this equation system for p_1^A and p_1^B yields

$$\begin{aligned} p_1^{A*} &= \frac{(3L+2\delta L+c_{II})(2+3\delta)+2c_I(1+\delta)(2+\delta)}{6+5\delta}-\delta r, \qquad (24) \\ p_1^{B*} &= \frac{(1+\delta)[(3L+c_I)(2+\delta)+4c_{II}]}{6+5\delta}. \qquad (25) \end{aligned}$$

In Proposition 4 we have claimed that all consumers buy in the first period. We will show that Assumption 2 is sufficient to ensure market coverage for the asymmetric case. All consumers buy in the first period if (and only if)

$$r-\sigma^{A*}L-p_1^{A*}\geq 0 \Leftrightarrow c_{II}<\tilde{c_{II}}=\frac{r(6+5\delta)-(3+2\delta)(3L+c_I)}{3}. \qquad (26)$$

Since we consider the marginal consumer at $\sigma^{A*}L$, this condition is equivalent to $[r-\sigma^{B*}L](1+\delta)-p_1^{B*}\geq 0$. Under Assumption 2, this condition always holds because $\tilde{c_{II}}>\hat{c_{II}}$:

$$\Leftrightarrow \quad \frac{6r+5\delta r-9L-3c_I-6\delta L-2\delta c_I}{3}>\frac{2r-3L+2\delta r-3\delta L}{2}$$

$$\Leftrightarrow \quad (r-c_I)(6+4\delta)>9L+3\delta L \qquad (27)$$

Assumption 1 is equivalent to $r-c_I>2L$. Thus the left-hand side of the expression is greater than $12L+8\delta L$ and thus greater than the right-hand side. Q.E.D.

Proof of Proposition 5: First, consider the symmetric equilibrium with $d^A = d^B = 1$. Making use of profits $\Pi(1,1)^*$ and $\Pi^B(1,2)^*$, as stated in Proposition 2 and Proposition 4, we get

$$\Pi(1,1)^* = \frac{L^2(2+\delta)}{4} \geq \Pi^B(1,2)^* = \frac{(2+\delta)[\beta - c_{II}]^2}{(6+5\delta)^2}. \tag{28}$$

This expression can be written as

$$\gamma \geq (\beta - c_{II})^2, \tag{29}$$

with $\beta = (3L + c_I)(1+\delta)$ denoting the upper bound of c_{II}, as stated in Assumption 3, and $\gamma = L^2(6+5\delta)^2/4$. Solving as equation yields

$$c_{II} = \beta + \sqrt{\gamma} \quad \wedge \quad c_{II} = \beta - \sqrt{\gamma}. \tag{30}$$

The first solution is invalid as $c_{II} > \beta$ would violate Assumption 3. Substituting back into the correct solution $c_{II} = \beta - \sqrt{\gamma}$ gives us

$$\begin{aligned} c_{II} &= (3L + c_I)(1+\delta) - \frac{L(6+5\delta)}{2} \\ &= \frac{\delta L}{2} + c_I(1+\delta) \end{aligned} \tag{31}$$

In the equilibrium with $d^A = d^B = 1$, marginal costs c_{II} must be greater than $\delta L/2 + (1+\delta)c_I$ because $\partial \Pi^B(1,2)^*/\partial c_{II} < 0$.

It remains to show the uniqueness of the equilibrium with $d^A = d^B = 1$. Making use of profits $\Pi(2,2)^*$ and $\Pi^A(1,2)^*$, as stated in Proposition 3 and respectively Proposition 4, we get

$$\Pi^A(1,2)^* = \frac{2(1+\delta)[c_{II} - \alpha]^2}{(6+5\delta)^2} \geq \Pi(2,2)^* = \frac{L^2(1+\delta)}{2} \tag{32}$$

This can be written as

$$(c_{II} - \alpha)^2 \geq \gamma, \tag{33}$$

where $\alpha = (1+\delta)c_I - L(3+2\delta)$ is the lower bound of c_{II}, as given in Assumption 3, and $\gamma = L^2(6+5\delta)^2/4$, again. Solving as equation yields

$$c_{II} = \alpha + \sqrt{\gamma} \quad \wedge \quad c_{II} = \alpha - \sqrt{\gamma}. \tag{34}$$

The second solution is invalid as $c_{II} < \alpha$ would violate Assumption 3. Substituting back into the correct solution $c_{II} = \gamma + \sqrt{\beta}$ yields

$$\begin{aligned} c_{II} &= (1+\delta)c_I - L(3+2\delta) + \frac{L(6+5\delta)}{2} \\ &= \frac{\delta L}{2} + c_I(1+\delta) \end{aligned} \tag{35}$$

Since $\partial \Pi^A(1,2)^*/\partial c_{II} > 0$, marginal costs c_{II} greater than $\delta L/2 + (1+\delta)c_I$ result in $\Pi^A(1,2)^* > \Pi(2,2)^*$. Hence, $d^A = d^B = 1$ is the unique equilibrium in this case. The symmetric equilibrium with $d^A = d^B = 2$ occurs if $c_{II} < \delta L/2 + (1+\delta)c_I$ because $\Pi(1,1)^* < \Pi^B(1,2)^*$ and $\Pi^A(1,2)^* < \Pi(2,2)^*$ holds in this case. Q.E.D.

Proof of Proposition 6: First, we consider social welfare for the case $d^A = d^B = 1$. Overall consumer surplus for the buyers of product A is given by

$$\begin{aligned} CS^A(1,1) &= \int_0^{L/2} [r - z - p_1^A(1,1)^*] d\tilde{z} + \delta \int_0^{L/2} [r - z - p_2^{A*}] d\tilde{z} \\ &= \frac{L[4(1+\delta)(r-c_I) - (5+3\delta)L]}{8}. \end{aligned} \tag{36}$$

Due to symmetry, social welfare can be written as

$$\begin{aligned} W(1,1) &= 2\,\Pi_A(1,1)^* + 2\,CS^A(1,1) \\ &= \frac{4L(1+\delta)(r-c_I) - L^2(1+\delta)}{4}. \end{aligned} \tag{37}$$

In the case $d^A = d^B = 2$, overall consumer surplus is equal to

$$\begin{aligned} CS^A(2,2) &= \int_0^{L/2} [r - z - p_1^A(2,2)^*] d\tilde{z} + \delta \int_0^{L/2} [r - z] d\tilde{z} \\ &= \frac{4(1+\delta)rL - 4c_{II}L - (1+\delta)5L^2}{8}. \end{aligned} \tag{38}$$

Social welfare is given by

$$\begin{aligned} W(2,2) &= 2\,\Pi_A(2,2)^* + 2\,CS^A(2,2) \\ &= \frac{4(1+\delta)rL - 4c_{II}L - (1+\delta)L^2}{4}. \end{aligned} \tag{39}$$

Finally, comparing $W(1,1)$ with $W(2,2)$, we get

$$W(1,1) > W(2,2) \quad \Leftrightarrow \quad c_{II} > c_I(1+\delta). \tag{40}$$

Q.E.D.

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