Planned Obsolescence and the Provision of Unobservable Quality

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April 19, 2006

Abstract

This paper develops the idea that obsolescence acts as an incentive device to provide quality for experience goods. The argument is that obsolescence affects the frequency at which consumers repurchase products and may punish producers for a lack of quality. A higher rate of obsolescence enables a firm to convince its consumers that it provides high quality. We identify a trade–off between quality and durability, implying that the two are substitutes. This leads to excessive obsolescence. The inefficiency is due to unobservability and not monopolistic distortions. The theory follows naturally from the theory of repeated games.

Keywords: Obsolescence, unobservable quality, reputation, repeated games
JEL Classification No.: L15, D21

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1 Introduction

> "The iPod is an example of the kind of poor design and obsolescence that's occurring in the electronics industry" - Shelia Davis of the Silicon Valley Toxics Coalition.[1]

In October, 2001, Apple introduced its most successful product ever, the iPod, a highly portable digital audio player. Consumers praise the iPod for its ease of operation and design. Yet, in one important dimension the iPod's quality has been lacking: durability. In 2003 Apple acknowledges that the iPod's battery has a limited lifetime and is irreplaceable. After its failure consumers need to buy a new device, or use Apple's out–of–warranty battery replacement program for $99 dollars.[2] The company defends its high fee by explaining that, by design, it is cheaper to exchange the physical device than to replace only the battery.

This raises the question why Apple, with its high concern for quality in other dimensions, has chosen to limit the device's lifetime with something as simple as an irreplaceable battery. Although consumers are now well aware of the limited lifetime, Apple remains ardently committed to the irreplaceable battery and excessive replacement costs: also newer iPod versions have irreplaceable batteries. As a response, multiple third parties have started selling iPod battery replacement kits.[3] Yet, Apple's commitment to the irreplaceable battery remains unbroken. In its recent iPod Nano version, Apple solders the battery to the device and, in the new Video iPod, the battery is physically affixed to the metal backplate. This makes a replacement by the consumer all but impossible.

The iPod's irreplaceable battery is an example of planned obsolescence and suggests that the iPod is an inefficient product. This would make the iPod's success even more remarkable and raises questions about market efficiency. How come that an inefficient product may thrive, let alone survive, in a market as competitive as the market for audio players? Why doesn't

[1] http://www.detnews.com/2005/technology/0503/09/A08-111726.htm.

[2] Originally, the replacement cost 250 dollars (http://www.ipodsdirtysecret.com). In August 2005, Apple reduced the price from $99 to $59 dollars.

[3] Source: http://en.wikipedia.org/wiki/IPod#Battery_life

the competition drive the iPod from the market by offering a similar product with a more efficient lifetime? Competitors have indeed tried to do so. For instance, the most distinguishable feature in Creative's advertisement of its "Nomad Jukebox Zen NX" audio player was the "removeable, high–capacity Li-ion battery".[4] Why have the market's attempts to correct the iPod's inefficient levels of durability been unfruitful? This paper provides an answer to these questions. It develops a new, simple theory of planned obsolescence which argues that reduced durability may actually be in the interest of consumers: Planned obsolescence strengthens the producer's incentives to provide adequate quality in other dimensions than durability alone. In the case of the iPod, it helps Apple to maintain its highly acclaimed standards in design and ease of operation.

The explanation is as follows. Consider a producer who produces a good with an endogenous quality level that becomes only observable to a buyer after consumption. If the producer and buyer meet only once, the producer does not have an incentive to deliver appropriate quality. Klein and Leffler (1981) and Shapiro (1983), however, argue that when the producer produces repeatedly, he may develop a reputation for high quality. Hence, repeated interactions may lead to an appropriate provision of quality. The potential of reputation in providing quality depends on the frequency of these interactions. Since obsolescence affects this frequency, the reputation motive provides a theory of planned obsolescence. This paper confirms this idea and demonstrates that it leads to a trade–off between durability and other quality aspects.

The question of excessive obsolescence has been on the economists' research agenda for a long time and dates back to at least Wicksell (1923). Focusing on monopolists, earlier theories concluded, quite surprisingly, that the typical monopolist does not have an incentive to distort a product's lifetime. This counter–intuitive result was first shown by Swan (1970), who demonstrates that, even though a monopolist has an incentive to distort the quantity/price decision, he does not have an incentive to distort a product's lifetime. Schmalensee (1979) confirms the robustness of Swan's result and

[4] See http://www.nomadworld.com/products/jukebox_zen_nx/.

concludes that, even for a monopoly setting, a convincing theory of planned obsolescence requires a more elaborate setup. Such a setting is provided by Bulow (1982, 1986), who argues that the time–inconsistency problem of a durable monopolist identified in Coase (1972) induces a monopolist to choose excessive obsolescence. Most subsequent work on the issue of excessive obsolescence uses this framework (e.g. Waldman 1993, Choi 1994, Waldman 1996, Ellison and Fudenberg 2000, and Nahm 2004).

This paper proposes a theory of planned obsolescence based on repeated games rather than the time–inconsistency problem of Coase. It does not require the presence of a monopoly; it may also explain planned obsolescence under competition. The crucial ingredient of the theory is an unobservability of a quality characteristic different from durability. In this respect, it is related to Choi (2001), where firms may use observable durability as a signal for unobservable quality. A fundamental difference is, however, that in Choi's framework reduced durability is a signal rather than an incentive device. Moreover, Choi's signalling idea requires that durability is observable, whereas we explicitly show that this is not needed in our framework. Our explanation also markedly differs from Grout and Park (2005), who argue how planned obsolescence may promote a good's secondary market and therefore may arise even under competition.

The rest of the paper is organized as follows. The next section sets up the model in which we illustrate our arguments formally. In order to make our arguments as transparent as possible, Section 3 studies first a simplified version of the model. Section 4 extends the analysis and explicitly demonstrates how planned obsolescence also arises under less stringent assumptions such as unobservable and costly durability. In the conclusion, we emphasize that our idea behind planned obsolescence holds in much broader settings such as word–of–mouth communication and relational contracting. Effectively, our idea is the simple observation that reduced durability raises the frequency of economic interactions and, therefore, makes reputation more effective.

2 The Setup

We illustrate our theory in the classical framework of durability as introduced by Kleiman and Ophir (1966). A firm produces a good that is characterized by a quality level q and a durability level d with the interpretation that a good (q, d) yields a consumer a utility stream of q for d time units. That is, the consumer's discounted utility of a good (q, d) is

$$v(q,d) \equiv \int_0^d qe^{-rt}dt = \frac{(1-e^{-dr})q}{r}, \tag{1}$$

where r is the common interest rate. Hence, we extend the durability framework of Kleiman and Ophir by introducing an additional quality attribute q that is different from durability. In our theory, this second attribute will not be directly observable. An example of an unobservable quality in the case of Apple would be the iPod's ease of operation, which consumers only learn during the day–to–day use of the device. Yet, even the iPod's design may be seen as an unobservable quality attribute. Only over time consumers will find out that the design is a "classic" and does not become boring or runs out of fashion.

There is a single consumer who requires at most one functioning unit of the product. This non–crucial, simplifying assumption enables us to demonstrate clearly the role of unobservable quality on the choice of durability. In particular, it eliminates the effect identified by Bulow (1982,1986) that a producer may use planned obsolescence to mitigate the Coasian time–inconsistency problem of a durable monopolist.

We make the following standard assumptions about the producer's cost function $c(q, d)$. It is twice differentiable, weakly increasing in both q and d, and convex in (q, d). Hence, $c'_q, c'_d, c''_{qq}, c''_{dd} \geq 0$. In order to strengthen our results, we assume that, from a productive perspective, quality and durability are complements, $c''_{qd} \leq 0$. Moreover, a quality level of zero is costless to provide and the marginal cost of quality at $q = 0$ is zero: $c(0, d) = 0$ and $c'_q(0, d) = 0$ for all $d \geq 0$. Consequently, there are no fixed costs and the average cost of quality is smaller than its marginal cost, $c(q, d)/q < c'_q(q, d)$. We further assume that the marginal cost of quality becomes infinite at an infinite level of quality: $c'_q(\infty, d) = \infty$ for all $d \geq 0$. Finally, at a quality of zero and a durability of zero the marginal cost of durability is zero: $c'_d(0,0) = 0$.

Given the consumer's preferences and the firm's production technology, the social surplus from a good with quality q and durability d is

$$s(q,d) \equiv v(q,d) - c(q,d) = \frac{(1-e^{-dr})q}{r} - c(q,d).$$

Since a product of durability d breaks down after a time interval d, the consumer has to repurchase the product every d periods. This implies that the overall discounted surplus of a stream of goods (q,d) is

$$S(q,d) \equiv \sum_{i=0}^{\infty} \left(e^{-rd}\right)^i s(q,d) = \frac{q}{r} - \frac{1}{e^{-dr}-1} c(q,d).$$

Let (q^*, d^*) represent the first best efficient product characteristics. That is,

$$(q^*, d^*) = \arg\max_{q,d} S(q,d).$$

The first order condition

$$c'_q(q^*(d), d) = \frac{1-e^{-dr}}{r}. \tag{2}$$

yields the socially efficient quality level $q^*(d)$ for some fixed level of durability d. Clearly, $q^* = q^*(d^*)$. Since the right–handside of (2) increases with d, it follows, from the firm's production technology, that the optimal quality $q^*(d)$ is increasing in d.[5] As a consequence, higher durability makes quality more socially desirable. Hence, from both a social and a productive perspective quality and durability are complements. We want to stress this fact, because the next section argues that when quality is an experience good, this basic economic relationship is overturned; under unobservability quality and durability are substitutes.

Our assumptions on $c(q,d)$ allow us to consider the extreme case that durability is costless to provide. Since the assumption increases the transparency of our arguments, Section 3 will first focus on this extreme. In

[5] By the implicit function theorem we may differentiate (2) with respect to d and find $\partial q^*/\partial d = (e^{-dr} - c''_{qd})/c''_{qq} > 0$.

Section 3 we, therefore, express the cost function simply as $c(q)$. Section 4 explicitly shows that qualitative results remain unchanged under the more natural assumption that costs depend on durability.

If durability is costless to provide, the social surplus $S(q, d)$ is maximized for a product of indefinite durability ($d^* = \infty$). Consequently, the first best quality is $q^* = \lim_{d\to\infty} q^*(d)$. Or, alternatively, satisfies

$$c'(q^*) = \frac{1}{r}.$$

3 Unobservable Quality

When quality q and durability d are both observable, a competitive market ends up producing the first best efficient good (q^*, d^*) and pricing it at its marginal costs $p = c(q^*)$. In our simple setup with inelastic demand, it is immediate that also a monopolist chooses efficient durability d^*.[6] More precisely, the monopolist produces the efficient good (q^*, d^*) and charges the monopoly price $p^m = v(q^*, d^*)$. Hence, under full observability our model does not generate planned obsolescence.

This section demonstrates that we obtain planned obsolescence if we only change our assumption concerning the observability of quality q. In particular, we assume that the consumer cannot observe the producer's quality q before purchase; he observes it only after consumption. In the terminology of Nelson (1970), the producer offers an experience good. As the consumer cannot observe the quality at the time of purchase, he will form some beliefs q^e about it. Since the consumer observes the price p and durability d, his beliefs q^e may, in general, depend on these observations.[7] Formally, the belief $q^e(d, p)$ is a function $q^e : \mathbb{R}^2_+ \to \mathbb{R}_+$.

Now suppose that the firm offers a good with efficient durability, i.e., with an indefinite durability ($d = \infty$). In this case, the consumer needs to purchase

[6]Swan (1970) shows that even when demand is elastic, a monopolist chooses the efficient level of durability d^*.

[7]Section 4 explicitly demonstrates that planned obsolescence also obtains when durability is also unobservable at the time of purchase.

the good at most once. For goods with indefinite durability, there exists no equilibrium in which the producer chooses a positive quality level and the consumer buys the product. Indeed, if such an equilibrium existed, it would mean that the producer chooses some quality $\tilde{q} > 0$, sold it at some price $\tilde{p}$, and the consumer's belief $q^e(\infty, \tilde{p})$ was such that $v(\infty, q^e(\tilde{p}, \infty)) \geq \tilde{p}$. This cannot be an equilibrium, because, given the consumer's beliefs and behavior, the producer could have gained by producing the good $(q, d) = (0, \infty)$ and charging the price $\tilde{p}$.

If the firm produces a good with a finite durability, $d < \infty$, the consumer must renew his purchase every d periods. The good's limited lifetime thereby changes the game into an infinitely repeated game. From the theory of infinitely repeated games it is well known that, depending on the discount factor, positive levels of quality may be sustainable. By using appropriate trigger strategies the consumer induces the firm to provide adequate levels of quality. This section investigates this idea and studies to what extent the possibility of repeated purchases may sustain positive levels of quality.

Formally, we consider a repeated game that is preceded by an initial stage, where the seller chooses some observable, fixed durability d. The assumption that durability is observable and chosen once–and–for–all at the beginning of the game is made for expositional reasons only. Section 4 explicitly shows that these two assumptions are inconsequential.

After durability has been chosen, the seller and buyer play an infinitely repeated version of the following stage game: First, the seller sets a price p. Upon observing the price p, the buyer decides whether to buy the product. In case the buyer buys, the producer selects a quality q, produces the good (q, d), and incurs the costs $c(q)$. Thus, in each stage game the seller chooses as her strategy a price $p \geq 0$ and an unobservable quality $q \geq 0$, and the buyer's strategy, $b \in \{0, 1\}$, is to buy ($b = 1$) or not to buy ($b = 0$) the product. Then, for a given durability d, we have a stage game $\Gamma(d)$ with payoffs

$$u_s(q,p,b) = \begin{cases} p - c(q) & \text{if } b = 1; \\ 0 & \text{if } b = 0; \end{cases} \quad \text{and } u_b(q,p,b) = \begin{cases} v(q,d) - p & \text{if } b = 1; \\ 0 & \text{if } b = 0. \end{cases}$$

We may now construct the supergame $\Gamma^s(d)$ where the seller and the buyer play the stage game $\Gamma(d)$ every d periods. Since each stage lasts for d periods, the effective discount factor in the supergame $\Gamma^s(d)$ is $\delta = e^{-rd}$.

Within this framework we identify the combinations $(\bar{d}, \bar{q})$ such that the supergame $\Gamma^s(\bar{d})$ has an equilibrium outcome for which in each round the seller chooses $\bar{q}$, and some price $p \geq 0$, and the buyers always buys. Applying the arguments of Abreu (1988), we may identify the set of sustainable combinations $(\bar{d}, \bar{q})$ by considering the following trigger strategies:

Strategy $\sigma_s(\bar{p}, \bar{q})$: In the first period, the seller sets a price $\bar{p}$ and chooses a quality $\bar{q}$ if the buyer decides to buy. As long as the seller and the buyer have chosen $(q, p, b) = (\bar{q}, \bar{p}, 1)$ in all previous stages, the seller continues to choose a price $p = \bar{p}$ and a quality $q = \bar{q}$. Otherwise, he chooses $p = q = 0$.

Strategy $\sigma_b(\bar{p}, \bar{q})$: As long as the seller and the buyer have chosen $(q, p, b) = (\bar{q}, \bar{p}, 1)$ in all previous stages and the seller choose $p = \bar{p}$ in the current period, the buyer buys, i.e., chooses $b = 1$. Otherwise, he chooses $b = 0$.

The strategies $\sigma_s(\bar{p}, \bar{q})$ and $\sigma_b(\bar{p}, \bar{q})$ pin down behavior for any possible history in the game. They imply two modes of play: a cooperative mode during which the players choose $(q, p, b) = (\bar{q}, \bar{p}, 1)$ and a punishment mode with $(q, p, b) = (0, 0, 0)$.

The strategies $(\sigma_b(\bar{p}, \bar{q}), \sigma_s(\bar{p}, \bar{q}))$ yield the outcome $q = \bar{q}$, $p = \bar{p}$, and $b = 1$ with payoffs

$$U_b(\bar{q}, d, \bar{p}) \equiv \sum_{i=0}^{\infty} \delta^i \left(v(\bar{q}, d) - \bar{p}\right) = \frac{v(\bar{q}, d) - \bar{p}}{1 - \delta}; \tag{3}$$

for the buyer and

$$U_s(\bar{q}, d, \bar{p}) \equiv \sum_{i=0}^{\infty} \delta^i \left(\bar{p} - c(\bar{q})\right) = \frac{\bar{p} - c(\bar{q})}{1 - \delta}; \tag{4}$$

for the seller.

We now derive the conditions under which the strategy combination $(\sigma_b(\bar{p}, \bar{q}), \sigma_s(\bar{p}, \bar{q}))$ constitutes a subgame perfect equilibrium of the supergame

$\Gamma^s(d)$. By the single deviation principle it is sufficient to consider only single deviations. That is, one must verify that players may not gain from a single deviation in the cooperative or in the punishment phase. Since $(q, p, b) = (0, 0, 0)$ is a subgame perfect equilibrium of $\Gamma^s(d)$, players have no incentive to deviate in the punishment mode.

If the buyer deviates in the cooperative mode by playing $b = 0$, it yields the buyer a payoff of zero. Hence, the buyer has no incentive to deviate whenever $U_b(q, d, p) \geq 0$. Or, equivalently, whenever

$$\bar{p} \leq p_h(\bar{q}, d) \equiv v(\bar{q}, d) = (1 - \delta)\bar{q}/r. \tag{5}$$

Similarly, if the seller deviates in the cooperative mode, i.e., offers a quality different from $\bar{q}$, he receives a payoff

$$\bar{p} - c(q) - \sum_{t=1} \delta^t 0 = \bar{p} - c(q). \tag{6}$$

Hence, the deviation that maximizes his payoff is $q = 0$, leading to the payoff $\bar{p}$. It follows that the seller does not want to deviate if expression (4) exceeds $\bar{p}$. That is, if

$$\bar{p} \geq p_l(\bar{q}, d) \equiv c(\bar{q})/\delta. \tag{7}$$

We conclude that the supergame $\Gamma^s(d)$ has an equilibrium in which the combination (d, q) is sustainable if $p_h(d, q) \geq p_l(d, q)$. Recalling that $\delta = e^{-dr}$ this is equivalent to

$$f(q, d|r) \equiv (1 - e^{-dr})e^{-dr}q - c(q)r \geq 0. \tag{8}$$

It therefore follows that, for a given interest rate $r > 0$, the set

$$C(r) \equiv \{(q, d)|f(q, d|r) \geq 0\} \tag{9}$$

describes all sustainable combinations (q, d).

In order to identify the extreme combinations of (q, d), let $q(d)$ denote a curve defining the pairs $(q(d), d)$ for which inequality (8) is satisfied with

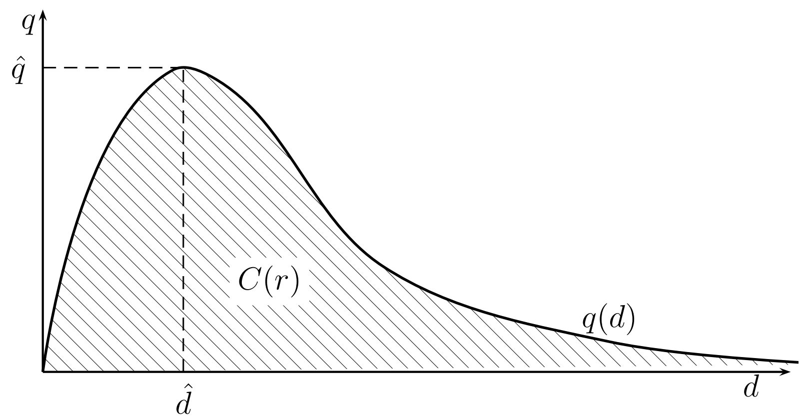

Figure 1: Sustainable product characteristics (q, d).

equality. In case there are multiple solutions, we are interested in the largest level of quality q.[8] Hence, we define

$$q(d) \equiv \max_q \{q | f(q, d|r) = 0\}.$$

Given a durability d, the curve $q(d)$ describes the maximum quality q that is sustainable. The following lemma shows that the function $q(d)$ is well–defined for $d \in (0, \infty)$ and attains a unique maximum.

Lemma 1 *The curve $q(d)$ is continuous and differentiable on $d \in (0, \infty)$. It is single peaked and attains a unique maximum of $\hat{q}$ at $\hat{d} = \ln 2/r$, where $\hat{q}$ satisfies $\hat{q} = 4rc(\hat{q})$.*

The proof of the lemma is relegated to the appendix. Figure 1 illustrates it graphically. Starting in (0,0) the curve $q(d)$ first increases and then decreases. This is due to two opposing effects. On the one hand, an increase in durability raises the buyer's willingness to pay, because, due to the product's longer lifetime, the overall utility which the buyer derives from it is higher. Hence, a higher durability enables the producer to charge higher prices so that the buyer's threat not to buy the good if the producer cheats is larger. Due to the stronger threats, higher levels of quality are sustainable. On the other hand, the increased durability implies that the buyer interacts less often with the

[8]E.g., (8) is satisfied with equality for any d whenever $q = 0$.

producer. Consequently, the buyer cannot react as quickly, when he realizes that the producer has not chosen the appropriate quality level. Hence, we obtain two opposing effects. An increase in durability raises, due to the first effect, the effectiveness of threats, but lowers it, due to the second effect. The lemma shows that, when durability is low, the first effect dominates. As durability rises, the second effect increases in relative importance. At a durability level $\hat{d}$ the two effects cancel out. For larger levels of durability the second effect dominates and the curve $q(d)$ is decreasing.

The set $C(r)$ identifies the sustainable combinations (q, d). The decreasing part of the curve $q(d)$ implies that durability and quality are substitutes. For larger levels of durability, one can only increase the good's quality if durability is reduced and vice versa. This contradicts our earlier observation that, under observability, durability and quality are complements. Hence, unobservability changes the economic relationship between durability and quality from complements to substitutes. It confronts the parties with a trade–off between quality and durability.

With respect to this trade–off, we may identify the constrained (second best) efficient solution (q^{**}, d^{**}, p^{**}) that maximizes the social welfare $S(q, d)$ under the condition that p^{**} sustains the combination (q^{**}, d^{**}) as an equilibrium. We obtain this second best solution by solving the following maximization problem:

$$\max_{q,d,p} S(q, d) \quad \text{s.t.} \quad p \in [p_l(q, d), p_h(q, d)]. \tag{10}$$

The next proposition characterizes the solution.

Proposition 1 *Whenever quality is unobservable, the constrained efficient solution* (q^{**}, d^{**}, p^{**}) *exhibits* $d^{**} < d^*$, $q^{**} < q^*(d^{**}) < q^*$. *It is fully characterized by* $p^{**} = p_l(q^{**}, d^{**})$, $f(q^{**}, d^{**}|r) = 0$, *and*

$$2r(c(q^{**})/q^{**} + c'(q^{**})) - 1 = \sqrt{1 - 4rc(q^{**})/q^{**}}.$$

The proposition shows that in the second best both durability and quality are suboptimally low in comparison to their first best level (d^*, q^*). As $q^{**} <$

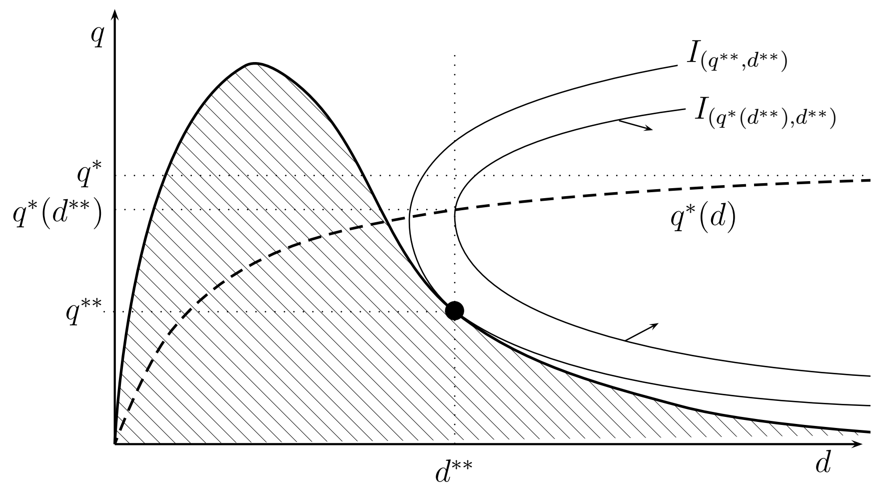

Figure 2: Unique second best efficient characteristics (q^{**}, d^{**}).

$q^*(d^{**}) < q^*$, the quality level q^{**} is distorted in two ways. It is suboptimally low, because d^{**} itself is lower ($q^*(d^{**}) < q^*$), but it is also suboptimally low given the durability level of d^{**} ($q^{**} < q^*(d^{**})$). A formal proof of this result is relegated to the appendix, but a heuristic argument can be given on the basis of Figure 2. The figure draws the set $C(r)$ of sustainable pairs (q, d) in relation to the iso–surplus functions. At the optimum (q^{**}, d^{**}), the corresponding iso–surplus curve $I_{(q^{**},d^{**})}$ is necessarily tangent to the curve $q(d)$. Since the slope of $q(d)$ is negative but finite, the iso–surplus curve $I_{(q^{**},d^{**})}$ is also finitely decreasing at (q^{**}, d^{**}). In contrast, the curve $I_{(q^*(d^{**}),d^{**})}$, which runs through the point $(q^*(d^{**}), d^{**})$, has, necessarily, an infinite slope at $(q^*(d^{**}), d^{**})$. From this it follows that $q^{**} < q^*(d^{**})$. Since $q^*(d)$ is increasing in d and $d^{**} < d^* = \infty$ it further follows that $q^*(d^{**}) < q^*$.

The proposition tells us what combination would be chosen by a social planner. In the remainder of this section we argue that this outcome is also an equilibrium outcome under both a monopoly and competition. First, we consider the monopoly setting. A monopolist will try to maximize his profits $U_s(q, d, p)$, but the consumer may find the quality q only credible for $p \in [p_l(q, d), p_h(q, d)]$. Hence, we may represent the principal's maximization problem by

$$\max_{q,d,p} U_s(q,d,p) \quad \text{s.t.} \quad p \in [p_l(q,d), p_h(q,d)]. \tag{11}$$

Since $U_s(q,d,p)$ is increasing in p, it is optimal for the monopolist to charge the price $p = p_h(q,d)$. Substitution yields $U_s(q,d,p_h(q,d)) = S(q,d)$. Effectively, the monopolist's maximization problem coincides with the social planner's maximization problem (10). We therefore arrive at the following result.

Proposition 2 *Suppose there exists a monopolist who operates with a cost function $c(q)$. Then there exist an equilibrium outcome, where in each round the consumer buys a good with characteristics (q^{**}, d^{**}) at a price p^{**}. The equilibrium profit of the monopolist is $U_s(q^{**}, d^{**}, p^{**})$.*

Finally we argue that, by a straightforward extension of the consumer's trigger strategy $\sigma_b(p^{**}, q^{**})$, the outcome (q^{**}, d^{**}, p^{**}) is also an equilibrium outcome with competition. To make this more precise, let there be n firms, who each can produce a good (q,d) with the same cost function $c(q)$. In period 0 each producer $i = 1, \ldots, n$ fixes its level of durability d_i. In period 1 each producer i makes an offer p_i to the consumer. Subsequently, the consumer may accept some offer p_j of producer j. The selected producer j then select a quality q_j and incurs the production cost $c(q_j)$. The consumer observes the quality q_j only after consuming the good. Since the other producers, $i \neq j$, need not produce, they incur zero production costs. A new round begins after d_i periods, in which each producer i chooses a new price p_i upon which the buyer bases his decision whether and at which producer to repurchase the good. The selected producer chooses its quality, etc., etc.

Now consider the following straightforward extension of the consumer's trigger strategy $\sigma_b(p^{**}, q^{**})$. After observing durabilities $(d_1, \ldots, d_n)$ and prices $(p_1, \ldots, p_n)$ of the different firms, the consumer only buys from a producer who offers a durability d^{**} at a price p^{**}. If $k > 1$ producers offer durability d^{**} at a price p^{**}, the consumer randomizes between these k firms and singles out one specific producer j. The consumer continues to buy from this producer j only if all previous goods match the quality level q^{**} and producer j keeps on charging the price p^{**}. Otherwise, the consumer stops buying altogether.

Against this extended trigger strategy of the consumer, the durability choice d^{**} and playing strategy $\sigma_s(p^{**}, q^{**})$ in any ensuing subgame is an optimal response of a firm i. Note that the strategy's optimality is independent of the strategies of rival firms. Yet, in equilibrium, all firms choose the same strategy consisting of durability choice d^{**} and the strategy $\sigma(p^{**}, q^{**})$. Against these strategies of the firms, the consumer's strategy is indeed optimal. Hence, we obtain an equilibrium in which the consumer consumes a good (q^{**}, d^{**}) each period and the ex ante expected profit of a firm is $U_s(q^{**}, d^{**}, p^{**})/n$. We summarize these findings in the following proposition.

Proposition 3 *Suppose there exist n producers who compete with identical cost functions $c(q)$. Then there exist an equilibrium outcome, where in each round the consumer buys a good with characteristics (q^{**}, d^{**}) at a price p^{**}. The equilibrium profit of a firm is $U_s(q^{**}, d^{**}, p^{**})/n$.*

4 Unobservable and Costly Durability

This section explicitly shows that the results of the previous section also obtain under the more natural assumptions that 1) durability is costly to provide and 2) durability is an experience good that is chosen anew every period and only observed after consumption. We show that these assumptions yield again a trade–off between quality and durability that leads to inefficiently low levels of durability and quality. However, since costly durability makes the problem less tractable, the analysis is more abstract.

Following the analysis of the previous section, we may establish that a combination (q, d) is sustainable if and only if $p_l(q, d) \equiv c(q, d)/\delta^d \leq p_h(q, d) \equiv q(1 - \delta^d)/(1 - \delta)$ with $\delta = e^{-rd}$. That is, whenever

$$f(q, d|r) \equiv (1 - e^{-dr})e^{-dr}q - c(q, d)r \geq 0.$$

The set of sustainable pairs (q, d) is therefore

$$C(r) = \left\{(q, d) \in \mathbb{R}^2_+ \mid f(q, d|r) \geq 0\right\}.$$

As in the previous section, the function $f(q,d)$ and the set $C(r)$ play a crucial role. We therefore first study their structure and properties.

As before, we are interested in the curve $q(d)$ that is implicitly defined as

$$f(q(d), d|r) = 0.$$

A first lemma confirms that there actually exists a curve $q(d)$ in the positive quadrant $\mathbb{R}^2_+$. Consequently, the set of sustainable combinations, $C(r)$, is nonempty.

Lemma 2 *There exists a curve $q(d)$ that is increasing at $d = 0$.*

A second lemma shows that whenever a durability of degree $\bar{d}$ is sustainable with some quality $\bar{q}$, then a lower quality level, $q < \bar{q}$, is also sustainable with durability level $\bar{d}$. Combining this result with the previous lemma implies that there exists a unique curve $q(d)$ with the property $q(d) > 0$.

Lemma 3 *If $(\bar{q}, \bar{d}) \in C(r)$ with $\bar{q} > 0$, then $f(q, \bar{d}|r) > 0$ and $(q, \bar{d}) \in C(r)$ for all $q \in (0, \bar{q})$.*

We may now demonstrate the trade–off between durability and quality. In particular, the following result shows that for larger levels of durability the curve $q(d)$ is decreasing. Hence, we find again that durability and quality are substitutes.

Proposition 4 *The curve $q(d)$ is decreasing for $d \geq ln2/r$.*

With costly durability the first best efficient level of durability may be finite. This raises the possibility that the efficient combination (q^*, d^*) lies in the sustainable set $C(r)$. In this case, the second best efficient combination (q^{**}, d^{**}) coincides with the first best efficient combination (q^*, d^*) and we should not see downward distortions on durability. Indeed, this will occur in two economicly relevant situations. First, when the consumer values durability much more than other quality characteristics and, second, when the provision of durability is relatively expensive as compared to the discount rate r.

Hence, the explicit consideration of costly durability does not invalidate our theory. Instead, it highlights that our theory becomes relevant when consumers appreciate other quality characteristics than durability alone and when durability is not too costly to provide. Under such circumstances the first best efficient combination (q^*, d^*) will not be attainable and our trade–off becomes relevant. It leads to distortions both in the durability and the quality dimension.

5 Conclusion and Discussion

When quality is an experience good, reduced durability provides stronger incentives for the provision of quality. This leads to lower levels of durability than in a first best world where quality is observable. From a first best perspective, we may interpret these lower levels of durability as a planned obsolescence of consumption goods. Our theory is relevant in markets where durability is not too costly and consumers appreciate other quality aspects than durability alone. We view the market for portable media players as an example of such a market and motivated our theory with the artificially limited lifetime of Apple's iPod.

Our theory is based on the almost tautological idea that planned obsolescence implies that consumers have to repurchase their products more often. Consequently, it increases the speed at which consumers can retaliate against a producer who fails to deliver appropriate quality. Faster means of retaliation create stronger incentives for the producer not to cheat and these stronger incentives enable the producer to provide higher quality. Thus, we conclude that planned obsolescence acts as an incentive device for unobservable quality.

We formalized our arguments in a stylized model where the only way to induce appropriate quality was repeated purchases by a consumer. Yet, our observation that obsolescence is an incentive device for quality remains also valid if a firm's reputation is based on different mechanisms. For example, word–of–mouth communication is often regarded as an additional channel by which a firm may establish a reputation. For our theory, it is irrelevant whether a consumer bases his repurchase decision on his own experiences or, through word–of–mouth, on the past experience of other consumers. Increased obsolescence means that, in a given period, there will be more consumers who need a new product. This larger group of consumers can retaliate more forcefully when they learn, by word–of–mouth, that a producer cheated in some previous period. It makes cheating less profitable and reputation more effective.

Effectively, we argue that durability affects the discount factor in a repeated game and thereby the potential for cooperation. In the world of Klein and Leffler (1981), this insight yields a theory of planned obsolescence. However, our idea may also be utilized in other repeated games. For instance, we may apply it to the literature on implicit or relational contracting, where the enforcement of contracts is explicitly based on a repeated games argument (e.g., MacLeod and Malcomson 1989, Levin 2003). In these contexts, one may view the durability of a contract as determining the frequency at which contracting parties may discipline opportunistic behavior and our idea provides an argument in favor of short term contracting.

Appendix

Proof of Lemma 1: The implicit function theorem implies that the equation

$$(1 - e^{-dr})e^{-dr}q = c(q)r \tag{12}$$

defines q as a function of d everywhere on $(0, \infty)$ provided that for any (d_0, q_0) satisfying (12) it holds

$$c'(q_0) \neq \frac{(1 - e^{-d_0 r})e^{-d_0 r}}{r}$$

But this follows from

$$c'(q_0) > c(q_0)/q_0 = \frac{(1 - e^{-d_0 r})e^{-d_0 r}}{r}. \tag{13}$$

Hence, equation (12) defines $q(d)$ over $(0, \infty)$ with a well–defined derivative

$$q'(d) = \frac{(2e^{-dr} - 1)e^{-dr}qr}{rc'(q) - (1 - e^{-dr})e^{-dr}} \tag{14}$$

Inequality (13) implies that the denominator is positive. The sign of $q'(d)$ coincides with the sign of its numerator. Consequently, $q'(d)$ is positive for $e^{-dr} > 1/2$ and negative for $e^{-dr} < 1/2$. This implies that $q(d)$ obtains a unique maximum at

$$d = \hat{d} \equiv \frac{\ln 2}{r}.$$

Substitution of $\hat{d}$ into (12) yields

$$\hat{q} = 4rc(\hat{q}). \tag{15}$$

Q.E.D.

Proof of Proposition 1: Let (q^{**}, d^{**}) represent a solution to Problem (10). The objective function $S(q,d)$ is increasing in d. This implies, first, that the constraint (8) is binding at the optimum so that (q^{**}, d^{**}) lies on the curve $q(d)$. Second, it implies that $d^{**} \geq \hat{d}$. Inverting $q(d)$ for $d > \hat{d}$ yields

$$d(q) = \frac{\ln\left(1 + \sqrt{1 - 4rc(q)/q}\right) - \ln(2rc(q)/q)}{r}. \tag{16}$$

Substitution of d by $d(q)$ simplifies the maximization problem (10) to

$$\max_q \Pi(q) \equiv \frac{q + \sqrt{q(q - 4rc(q))}}{2r}.$$

The first order condition w.r.t. q yields the optimality condition

$$\Pi'(q) = 0 \;\Rightarrow\; 2r(c(q)/q + c'(q)) - 1 = \sqrt{1 - 4rc(q)/q}. \tag{17}$$

with the corresponding second order derivative

$$\Pi''(q) = -\frac{2r(c(q) - qc'(q))^2 + q^2(q - 4rc(q))c''(q)}{(q(q - 4rc(q)))^{3/2}}. \tag{18}$$

From $c''(q) > 0$ it follows that $q/c(q)$ is decreasing in q. Hence for all $q < \hat{q}$, it follows from (15) that $q/c(q) > \hat{q}/c(\hat{q}) = 4r$. Hence, the numerator and denominator in (18) are positive and, therefore, $\Pi''(q) < 0$ for all $q < \hat{q}$. As a consequence, the second order condition is satisfied for any $q < \hat{q}$ and the derivative $\Pi'(q)$ is falling in q for $q \in (0, \hat{q})$. But then, since $\lim_{q \to 0} \Pi'(q) = 1/r > 0$ and $\lim_{q \to \hat{q}} \Pi'(q) = -\infty$, there must, due to continuity, exist a

$q^{**} \in (0, \hat{q})$ such that $\Pi'(q^{**}) = 0$. Since q^{**} satisfies the first and second order condition, it is a maximizer of $\Pi(q)$. Finally, $d^{**} = d(q^{**}) > 0$.

Since $d^* = \infty$, the existence of a finite solution (q^{**}, d^{**}) implies that $d^{**} < d^*$. As $q^*(d)$ is increasing in d, it follows $q^*(d^{**}) < q^*(d^*) = q^*$. It remains to prove that $q^{**} < q^*(d^{**})$.

First, from (2) it follows

$$e^{-d^{**}r} = 1 - rc'(q^*(d^{**})). \tag{19}$$

Since $d^{**} > \hat{d} = \ln 2/r$, equality (19) implies $c'(q^*(d^{**})) > 1/(2r)$. Second, since $f(q^{**}, d^{**}) = 0$, it follows

$$(1 - e^{-d^{**}r})e^{-d^{**}r} = c(q^{**})r. \tag{20}$$

Due to $c'(q^*(d^{**})) > 1/(2r)$, we may use (19) to rewrite (20) as

$$2rc'(q^*(d^{**})) - 1 = \sqrt{1 - 4c(q^{**})r/q^{**}}. \tag{21}$$

Finally, since q^{**} satisfies the first order condition (17) we may use (21) to rewrite (17) as

$$c'(q^*(d^{**})) - c'(q^{**})) = c(q^{**})/q^{**} > 0. \tag{22}$$

Since $c''(.) > 0$, this implies $q^{**} < q^*(d^{**})$. Q.E.D.

Proof of Lemma 2: The curve $q(d)$ is increasing at $d = 0$ if $q'(0) = \lim_{d \to 0} q'(d) > 0$. L'Hopital's rule implies

$$q'(0) \;=\; \lim_{d \to 0} q'(d) = \frac{q'(0) - c''_{qd}(0,0)q'(0) - c''_{dd}(0,0)}{c''_{qd}(0,0) + q'(0)c''_{qq}(0,0) - 1}. \tag{23}$$

Thus, we obtain a quadratic equation in $q'(0)$ with the two roots

$$q'(0) = \frac{1 - c''_{qd}(0,0) \pm \sqrt{(1 - c''_{qd}(0,0))^2 - c''_{dd}(0,0)c''_{qq}(0,0)}}{c''_{qq}(0,0)}$$

Convexity of $c(q, d)$ implies that ${c''_{qd}}^2 - c''_{dd}c''_{qq} \geq 0$. Combining this with $c''_{qd} \leq 0$ implies that the square root exists. Moreover, the denominator of the expression is positive so that the sign of $q'(0)$ depends on the sign of the numerator. The numerator may be rewritten as $a \pm \sqrt{a^2 - b}$, where

$a \equiv 1 - c''_{qd}(0,0) > 0$ and $b \equiv c''_{dd}(0,0)c''_{qq}(0,0) > 0$. Hence, the positive root is positive, because $a + \sqrt{a^2 - b} \geq a > 0$. Consequently, $q'(0) > 0$. Q.E.D.

Proof of Lemma 3: From $c'_q(q,d) \geq c(q,d)/q$ it follows

$$\frac{\partial}{\partial q}\left(\frac{c(q,d)}{q}\right) = \frac{c'_q(q,d) - c(q,d)/q}{q} \geq 0$$

and, therefore, $c(q,d)/q$ is increasing in q. Let $(\bar{q},\bar{d}) \in C(r)$. Then, for any $q \in (0,\bar{q})$ it follows

$$\frac{c(q,\bar{d})}{q} \leq \frac{c(\bar{q},\bar{d})}{\bar{q}} \leq \frac{(1-e^{-dr})e^{-dr}}{r}.$$

Therefore, $f(q,\bar{d}) \geq f(\bar{q},\bar{d}) \geq 0$ and $(q,\bar{d}) \in C(r)$ whenever $(\bar{q},\bar{d}) \in C(r)$. Q.E.D.

Proof of Proposition 4: By the implicit function theorem, $q(d)$ is well defined and differentiable whenever $f'_q(q(d),d) \neq 0$. For $d > 0$, this follows from $f'_q(q(d),d) = (1-e^{-dr})e^{-dr} - rc'_q(q(d),d) < (1-e^{-dr})e^{-dr} - rc(q(d),d)/q(d) = 0$. Hence, for $d > 0$ the curve $q(d)$ is differentiable at $(q(d),d)$ with derivative

$$q'(d) = -\frac{f'_d(q,d|r)}{f'_q(q,d|r)} = \frac{(2e^{-dr}-1)e^{-dr}qr - rc'_d(q,d)}{rc'_q(q,d) - (1-e^{-dr})e^{-dr}}$$

Due to $c'_q(q,d) > c(q,d)/q = (1-e^{-dr})e^{-dr}/r$, the denominator of $q'(d)$ is positive. The sign of $q'(d)$ coincides therefore with the sign of the numerator, which for $d > \ln 2/r$ is negative. Q.E.D.

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