Damaged Durable Goods[1]

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Abstract

A durable-goods monopolist may use quality degradation as a commitment not to lower price in the future. The introduction of damaged goods expedites low-valuation consumers' future demands, and helps the firm to mitigate the Coasian time-consistency problem. In such a case, damaged goods are more likely to be observed relative to the static setting where only the price-discrimination aspect of quality degradation is in effect. However, it is more likely to reduce welfare by inducing low-valuation buyers to buy the low-quality good early rather than to wait and buy the high-quality good later. So, quality degradation of durable goods is more likely to occur but less promising to the society, relative to the case of non-durable goods where damaged goods are rarely observed but more likely to be Pareto-improving.

Key Words: Damaged Goods, Quality Degradation, Durable-Goods Monopoly, Time-Consistency.

JEL Classification : D42, L12, L15

1 Introduction

Firms often introduce damaged goods by intentionally reducing the quality of the existing original good, even in cases producing the damaged good is more or at least as costly as the original one. Examples are widespread in both manufacturing and service industries: Intel 486SX microprocessor with disabled math coprocessor on the original 486DX microprocessor, IBM LaserPrinter E with firmware slowing the printing speed of the original LaserPrinter, Sony 64-minute recordable Minidiscs with some recording space being disabled, stripped-down versions of computer software (e.g. student versions with slow processing speed or functional limitations, read-only or play-only versions of Internet media tools, and so on), and Pex and Apex airfares with additional restrictions on normal economy fares.[1] This phenomenon is somewhat different from the traditional quality differentiation model à la Mussa and Rosen (1978), where goods of different quality are treated independently and the production cost is mostly increasing in quality. First, differentiation here comes from degradation: firms first develop a good of certain quality, and then introduce damaged goods even though there is no cost savings in reducing quality.[2] So, price differences can be justified only by price discrimination not by cost differences, and the price discrimination aspect is stronger than the standard quality differentiation. Second, the standard quality differentiation model, which is mainly focused on endogenising quality leading to the well-known downward quality distortion result, is technically ill-suited to analyse quality degradation in the sense that it always yields a non-differentiation solution under the cost structure characterising quality degradation, i.e. offering a single quality to a range of high-valuation consumers and excluding all the remaining consumers.

Denekere and McAfee (1996) was the first to formalise the phenomenon of damaged goods, focusing on the static price discrimination aspect of quality degradation. Allowing for a richer class of consumer preferences than the standard model, they show that introducing a damaged good can be not only profitable to the firm but also Pareto-improving. As the authors pointed out, however, the condition for introducing a damaged good to be profitable is somewhat unnatural and fails in many specifications of the environment, including the typical linear utility structure employed in the standard quality differentiation model.[3] Roughly speaking, the profitable in-

[1] Most of the examples cited here are taken from Denekere and McAfee (1996). See also Shapiro and Varian (1999) for more examples.

[2] In fact, in some cases such as IBM LaserPrinter E, the degraded good is clearly more expensive to produce than the original good.

[3] I mean by the linear utility structure that the marginal utility for quality is proportional to

troduction of a damaged good requires high-valuation consumers suffer much more from quality reduction than low-valuation consumers so that the firm can increase the sales to low-valuation consumers without losing high-valuation consumers' demand for the original product very much.[4] It naturally means that the conditions guaranteeing a Pareto-improvement are quite stringent as well. This observation suggests that the price discrimination role alone may not be fully satisfactory to explain the existence of the numerous examples of damaged goods.

Using a simple model, this paper analyses a durable-goods monopolist's incentive for quality degradation and its welfare effect in an intertemporal framework, and compare the results with the ones obtained in the static case with non-durables. In fact, many of the damaged-good examples introduced above can be considered as a durable good. It is well-known that a durable-goods monopolist faces a time-inconsistency problem. Without commitment to future pricing policy, it has the incentive to lower the price after selling to customers with high willingness-to-pay for the good, but this leads rational customers to postpone purchases. This time-consistency constraint limits the firm's monopoly power, and in its extreme form the monopoly profit goes to zero if all trade takes place in the twinkling of an eye, as conjectured by Coase (1972) and proved formally by Bulow (1982), Stokey (1981), and others.

In such a context, quality degradation can be used as a device to alleviate the Coasian time-inconsistency problem under a certain condition. By introducing a damaged good the firm induces low-valuation consumers to purchase the damaged good early rather than waiting and buying the original good later, which allows the firm to credibly commit not to reduce the price in the future provided there is no upgrade possibility for the early buyers of the damaged good.[5] This intertemporal consideration gives the firm another motivation to introduce damage goods, in addition to the static price discrimination discovered by Denekere and McAfee (1996). Note that the intertemporal commitment role of the damaged good is always beneficial to the firm since the monopolist would be better-off with the absence of

consumer type.

[4] Ambjørnsen (2002a) considers a somewhat different case. Within the standard utility structure as in Mussa and Rosen (1978), he shows that quality degradation may be a profitable strategy if consumers with large marginal utilities for quality to have greater outside options (i.e. high-valuation consumers have a lower willingness-to-pay than low-valuation consumers for some low qualities).

[5] Of course, there are other means and practices a durable-goods monopolist can employ to overcome the time-inconsistency problem. See, for instance, Bulow (1986), Butz (1990), and Kuhn and Padilla (1996).

low-valuation consumers, while the static price discrimination can be harmful depending on the consumer preference structure as mentioned above. As a result, the durable-goods monopolist has a greater incentive to introduce a damaged good than a static monopolist: even if the effect of price discrimination on profits is negative, a durable-goods monopolist may be still willing to introduce the damaged good provided the benefit from mitigating the time-consistency problem is sufficiently large.[6] However, the welfare consequence of quality degradation is less promising relative to the static case. Quality degradation of durable goods reduces welfare if low-valuation buyers, who would get a larger gross surplus by waiting and buying the original good later, are induced to buy the damaged good early. In particular, we find that the profitable introduction of the damaged good is always welfare-reducing under the linear utility structure employed in the standard quality differentiation model. This contrasts with the results obtained in the static model under the same parametric specification: the firm introduces the damaged good under very stringent conditions, but once it is introduced a Pareto-improvement is likely to occur. The discrepancy is mainly due to the different ways quality degradation affects low-valuation consumers in the two regimes: in the static setting low-valuation buyers who would not be served without quality degradation can consume at least the damaged good, while in the intertemporal setting they are induced to purchase the low-quality good early instead of buying the high-quality good later.

There are a small number of recent papers considering a durable-goods monopolist's optimal product-line design in the standard quality differentiation framework. Inderst (2002) shows that time consistency erodes the value of quality as a sorting variable, and in the extreme case the firm may wish to serve the whole market immediately. Takeyama (2002) discusses the time-inconsistency problem created by the future upgrade possibility for the early buyers of low-end products, which may force the firm to strategically boost the qualities of low-end goods as a means of committing to not providing future upgrades. Both authors also point out the possibility that low-quality goods are sold below costs. Unlike those work, we assume that quality is exogenously given as in Denekere and McAfee (1996). Rather than characterising the optimal quality, we focus on investigating how the firm's incentive for quality degradation is related to the consumer preference structure, and how it is different in the static and intertemporal regimes. Furthermore and more importantly,

[6] In case the degraded good fails to serve as a commitment device, the incentive for quality degradation will be smaller relative to the static case since the firm now faces an additional (intertemporal) incentive constraint as will be shown later. In fact, in the present model it turns out that the durable-goods monopolist has no incentive to introduce a degraded good in such a case.

we are interested in the welfare consequences of quality degradation rather than its product differentiation aspect, which is largely ignored in earlier work. On the other hand, a sequential introduction of horizontally differentiated products may also help the durable-goods monopolist mitigate the time-inconsistency problem by credibly deferring sales to low-valuation buyers, as shown by Courty (1998). Also related is the literature on product upgrades in a durable-goods monopoly, in which the main concern is whether the firm has the socially optimal incentive for upgrades under the time-consistency constraint (see, for example, Waldman (1993), Choi (1994), Fudenberg and Tirole (1998), Lee and Lee (1998), Ellison and Fudenberg (2000), and Ambjørnsen (2002b)). In contrast, the present paper is concerned with downgrades, which are often more cost-effective than upgrades in designing a product-line.

2 The model

A simple model with two types of buyers and two transaction periods will be useful to capture the main insights of quality degradation under the time-consistency constraint.

Supply Side: A monopolist sells durable goods over two periods. The firm has an original good of certain quality, and may introduce a damaged good at some point of time by reducing the quality of the original good. We assume that the quality of the damaged good is also given exogenously by some technological constraints. The marginal production cost is constant and is given as $c \geq 0$ for both goods.[7] We ignore fixed costs of production, and assume that there is no possibility of upgrades or technological innovations during the time horizon considered.

Demand Side: There are two groups of buyers with different valuations of the goods. A buyer has a type $\theta \in \{h, l\}$, which is private information. There is a continuum of buyers of each type, where the measure of type h is $\mu > 0$ and the measure of type l is $1 - \mu$. So, buyers act as price takers. Buyers have unit demands for either the original or damaged good in a single period. Both goods last at most two periods. The good purchased and used during period 1 can be used again in period 2 without depreciation. For simplicity, we assume that after period 2 the good becomes obsolete or is replaced by a new product. A type-θ buyer's per-period

[7] It would be more natural to allow for costly degradation by assuming either some fixed costs of degradation or a higher marginal cost for the damaged good. However, introducing degradation costs would not alter our conclusions.

valuation is

$$V_\theta = \begin{cases} v_\theta & \text{for the original good} \\ u_\theta & \text{for the damaged good} \end{cases},$$

where $v_l < v_h$, $u_l < u_h$, $u_h < v_h$, $u_l < v_l$, $v_h - v_l > u_h - u_l$, $v_l \geq c$, and $2u_l \geq c$. Let us define

$$R_o \equiv \frac{v_l}{v_h} \text{ and } R_d \equiv \frac{u_l}{u_h},$$

where R_o and R_d each denotes the valuation ratio between the two types for the original and the damaged good. By comparing the two ratios we can measure how the two types of buyers react differently to the quality variation. A useful reference is the linear utility structure employed in the standard quality differentiation model (i.e. $R_o = R_d$). Then, we can say that type-h buyers suffer *relatively* more from quality reduction than type-l buyers for the case of $R_o < R_d$, and conversely for the case of $R_o > R_d$. So, we allow for a much richer class of consumer preferences which includes the one considered in the standard model as a special case.

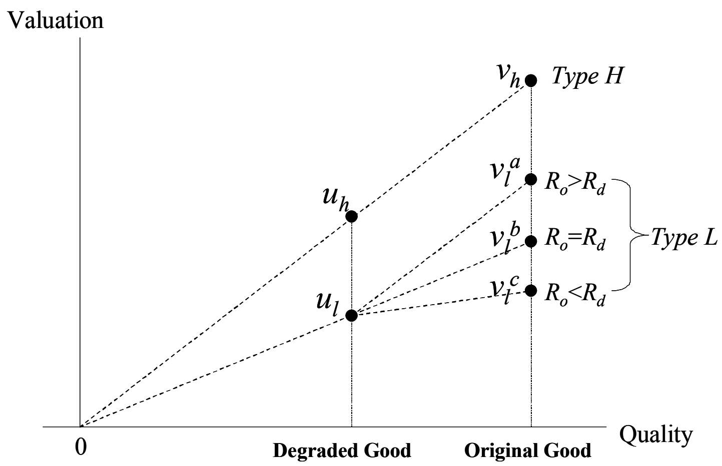

Figure 1: Three typical cases of the preference structure.

For simplicity, we rule out time discounting (i.e. the firm and the buyers care much about intertemporal issues). Buyers purchase if they are indifferent between buying and not buying. We employ the following assumption in order to focus on the time-inconsistency issue in the spirit of the classical durable-goods monopoly problem:

A1) $R_o \equiv \dfrac{v_l}{v_h} < \mu$

This assumption simply says that the valuation of the original good is sufficiently differentiated between the two types of buyers or the fraction of type-h buyers is sufficiently large so that the monopolist, when selling the original good alone, prefers intertemporal sales (i.e. selling to type-h buyers in the first period and to type-l buyers in the second period) to selling to both types of buyers in the first period.[8]

3 Quality degradation under commitment

This section analyses the incentive for quality degradation when the monopolist can make credible commitments to its future pricing and product introduction strategies.

- Equilibrium without the damaged good:

Consider first the case where the firm does not introduce the damaged good (selling the original good only). With commitment to future prices, this is exactly the same as renting the original good over the two periods. The firm has two options: sell to type-h buyers only at price $2v_h$ and get profits of $\mu[2v_h - c]$, or sell to both types at price $2v_l$ and get profits of $2v_l - c$. Under Assumption 1, the firm will choose the former option, and the resulting profit is given by

$$\Pi \equiv \mu[2v_h - c].$$

- Equilibrium with the damaged good:

Next consider the case where the firm introduces the damaged good. Given that $v_h - v_l > u_h - u_l$, the firm clearly wishes to induce high-valuation (type-h) buyers to purchase the original high-quality version and low-valuation (type-l) buyers to purchase the damaged low-quality version. Again, with commitment the firm's problem is the same as renting, and therefore essentially identical to the static damaged-goods model of Denekere and McAfee (1996). Let p_o and p_d denote the price of the original good and the price of the damaged good. As usual in the standard screening model, the firm will fully extract type-l buyers' surplus by charging $p_d^* = 2u_l$. From the incentive constraint of type-h buyers, $2v_h - p_o \geq 2u_h - p_d^*$, the optimal price for the original good is given by $p_o^* = 2v_h - 2(u_h - u_l)$.

[8] If Assumption 1 is violated, the market is cleared immediately in period 1. Then, without any time-consistency constraint the problem essentially reduces to the static model, and the comparison of the intertemporal and static cases is meaningless.

All sales occur in the first period, and the firm will optimally commit to no sales in the second period. The resulting profit is

$$\begin{aligned}\Pi^D &\equiv \mu[p_o^* - c] + (1-\mu)[p_d^* - c] \\ &= 2\mu v_h - 2(\mu u_h - u_l) - c.\end{aligned}$$

Type-h buyers get net surplus of $2(u_h - u_l)$ in the equilibrium. Note that the perfect price discrimination would be feasible if the valuation for the damaged good were the same for both types, i.e. $u_h = u_l$.[9] The following proposition summarises the firm's incentive for quality degradation and its welfare consequence in the commitment regime, which is qualitatively similar to the results obtained in Denekere and McAfee (1996) with a continuum of consumer types.

Proposition 1 *With commitment to future pricing, i) the firm introduces the damaged good if and only if*

$$2(u_l - \mu u_h) > (1-\mu)c, \tag{1}$$

and ii) the introduction of damaged good leads to a (weak) Pareto-improvement.[10]

Proof. i) Immediate from the condition $\Pi^D > \Pi$.

ii) The firm is certainly better-off under condition (1). Type-l buyers are indifferent since they receive zero net surplus with the introduction of the damaged good (full surplus extraction), as the same as the case without the damaged good in which they in fact do not purchase any goods. Type-h buyers, however, become strictly better-off: they get a strictly positive net surplus with the introduction of the damaged good, while zero net surplus would be obtained without it. Hence, the profitable introduction of the damaged good is weakly Pareto-improving. ■

Condition (1) simply says that the profit gain from selling to type-l buyers is greater than the profit loss from giving away some informational rents to type-h

[9] Ambjørnsen (2002a) makes a similar point in a model with different outside options for different types. In fact, in the equilibrium of his model the firm always achieves the perfect price-discrimination by choosing the quality of the degraded good at the level where the utility for the degraded good is the same between the high and low types.

[10] If Assumption 1 is violated, the firm will choose to sell to both types of buyers, and get profits of $2v_l - c$. It can be easily shown that in this case the static monopolist introduces the damaged good under a very strict condition similar to the one obtained here. But, quite obviously the welfare consequence is the opposite since the damaged good has no role of expanding the market. We ignore this uninteresting case, as in the Denekere and McAfee (1996).

buyers. Rearranging condition (1) using Assumption 1 leads to

$$R_d > \mu + \frac{(1-\mu)c}{2u_h} > R_o, \tag{2}$$

i.e. the profitable introduction of the damaged good requires that high-valuation consumers suffer much more from quality reduction than low-valuation consumers so that the firm can increase the sales without affecting high-valuation consumers' incentive constraint very much (i.e. without reducing the price of the original good very much). This condition is quite stringent, as mentioned earlier. For instance, it can be easily observed from condition (2) that quality degradation is never a profitable strategy under the linear utility structure employed in the standard quality differentiation model (i.e. $R_d = R_o < \mu$). However, if the damaged good is introduced it leads to a (weak) Pareto-improvement in this case. For expositional convenience, we will use the terms "static" and "commitment" interchangeably in the proceeding discussion.

4 Quality degradation without commitment

Suppose now that the firm cannot commit to its future pricing and product introduction strategies, and that renting is not permitted. Also, the potential buyers are assumed to have perfect foresight on future outcomes.

4.1 The standard case without the damaged good

We first consider the benchmark case where the monopolist does not consider introducing a damaged good, or quality degradation is prohibited by regulation. Then, our model is basically identical to the standard durable-good monopoly model *á la* Bulow (1982).[11] As usual in the literature, we use subgame perfection as our equilibrium concept. Under Assumption 1, the firm will induce type-h buyers to purchase in the first period and type-l buyers to purchase in the second period. Let p_1 and p_2 denote the first-period and the second-period price of the original good. The participation constraint of type-l buyers determines the optimal second-period price as $p_2^* = v_l$. The incentive constraint of type-h buyers is then given by $2v_h - p_1 \geq v_h - p_2^*$.

[11] By assuming a continuum of buyers, we rule out the perfectly discriminating equilibria proposed by Bagnoli, Salant, and Swierzbinski (1989, 1995) (see von der Fehr and Kühn (1995) for more details on how the relative commitment power between the seller and buyers affects the equilibrium outcome).

So, the optimal first-period price will be determined at $p_1^* = v_h + v_l$, and the resulting Coasian profit is given as

$$\begin{aligned}\pi^c &\equiv \mu[p_1^* - c] + (1-\mu)[p_2^* - c] \\ &= \mu v_h + v_l - c.\end{aligned}$$

In the equilibrium, type-h buyers get net surplus of $(v_h - v_l)$ and type-l buyers get zero net surplus.

4.2 Introducing the damaged good

Since the premium a type-h buyer is willing to pay for the increase in quality of the original good over the damaged good is higher than a type-l buyer, the firm will find it optimal to sell the original high-quality good to type-h buyers in the first period in any circumstances. Then, the introduction of the damaged good must happen in the first period. Introducing it in the second period, after selling the original good to type-h buyers, is time-inconsistent (not credible). So, the only relevant scenario here is that the firm sells both goods in the *first* period, the original good to type-h buyers and the damaged good to type-l buyers. Without commitment, however, the firm may have incentives to sell the original good in the second period, given that type-l consumers who bought the damaged good in the first period have replacement demands for the original good in the second period. With the damaged good already in hand, however, their willingness to pay for the original good in the second period is limited to the incremental valuation of the original good relative to the damaged good $(u_h - u_l)$. We have two strikingly different results in terms of the firm's degradation incentive, depending on the equilibrium outcome in the second-period subgame.

4.2.1 When $v_l - u_l \leq c$ (hardware)

This corresponds to the cases where the marginal production cost exceeds type-l buyers' willingness-to-pay for the replacement. So, it naturally fits into hardware markets with significant marginal production costs. Note that it is optimal for the firm not to sell the original good to in the second period. So, the market is completely cleared in the first period, and the firm does not have to worry about time-consistency anymore.[12] Then, we have the exactly same outcome as the previ-

[12] This extreme result is valid only in the present two-type model. With a continuum of types, the time-inconsistency problem would still remain in some extent, even though it would be largely relaxed by quality degradation.

ous degradation equilibrium under commitment, and the equilibrium profit is given by

$$\pi^d \equiv \Pi^D = \mu 2v_h - 2(\mu u_h - u_l) - c.$$

Given the equilibrium prices p_o^* and p_d^*, type-l buyers have no incentive to wait until period 2 since their surplus would be fully extracted by the firm anyway in period 2. Neither type-h buyers have incentives to wait since they could not get net surplus larger than the one obtained in the current equilibrium. The following proposition is immediate from the condition $\pi^d > \pi^c$.

Proposition 2 *For $v_l - u_l \leq c$, the firm introduces the damaged good if and only if*

$$(\mu v_h - v_l) + 2(u_l - \mu u_h) > 0. \tag{3}$$

Comparing conditions (1) and (3), it is easily observed that condition (1) is *sufficient* for condition (3) to hold under Assumption 1. That is, if the firm would be willing to introduce the damaged good in the static or commitment regime, it always does in the intertemporal non-commitment regime. This is not surprising recognising that the intertemporal commitment role of the damaged good is always beneficial to the firm. That is, the sum of the profit gain from relaxing type-h buyers' incentive constraint and the profit loss from giving up the second-period sales of the original goods to type-l buyers (the first term in (3)) is strictly positive under Assumption 1. This result clearly suggests that quality degradation is more likely to occur in the intertemporal regime compared with the static regime, and this is mainly because the damaged good helps the firm mitigating the time-inconsistency problem. Even if quality degradation would not be profitable in the static setting, the intertemporal monopolist has incentives to introduce the damaged good provided the positive effect of commitment role dominates the negative effect of the price-discrimination. For instance, the durable-goods monopolist may wish to introduce the damaged good even if type-l buyers suffer *relatively* more from quality reduction than type-h buyers, in which case a static monopolist never introduces the damaged good.[13]

4.2.2 When $v_l - u_l > c$ (software)

This is the case where the marginal production cost is so small that the firm always has the incentive to sell the original good in the second period to type-l consumers,

[13] Condition (3) can be written as $R_d > \mu - \frac{\mu v_h - v_l}{2u_h}$. Then, given Assumption 1 we may have the case where $\mu > R_o > R_d > \mu - \frac{\mu v_h - v_l}{2u_h}$.

the early buyers of the damaged goods. So, this case is more appropriate to describe markets for software, where producing an extra unit of goods is virtually negligible. Here the effect of the second-period subgame equilibrium on the firm's total profit is not trivial as in the previous case. Given type-l consumers' replacement demands, the optimal second-period price for the original good will be $v_l - u_l$.[14] Then, rationally expecting the replacement possibility in the second period, type-l consumers would not be willing to pay p_d^* for the damaged good in the first period. In fact, the maximal first-period price the firm can charge for the damaged good is determined by the type-l consumers' per-period utility for the damaged good, u_l. Similarly, type-h consumers will rationally expect the price of the original good to decline in the second period. Then, when choosing the first-period price of the original good the firm has to consider their waiting option as well as the existing static incentive constraint:

$$2v_h - p_o \geq 2u_h - u_l \quad : \text{type-}h\text{'s static } IC$$

and

$$2v_h - p_o \geq v_h - (v_l - u_l) \quad : \text{type-}h\text{'s intertemporal } IC \ .$$

If $v_h - v_l > 2(u_h - u_l)$, the intertemporal IC is binding and the static IC is not, and therefore the optimal first-period price of the original good is given as $v_h + (v_l - u_l)$. Otherwise, the opposite is true, and the optimal first-period price of the original good is given as $2v_h - (2u_h - u_l)$. It can be easily shown that the total profit with quality degradation is always smaller than the Coasian profit in both cases.

Proposition 3 *For $v_l - u_l > c$, the firm has no incentive to introduce the damaged good.*

Proof. When the type-h buyers' intertemporal IC is binding, the firm's profit is given by

$$\widetilde{\pi}^d \equiv \mu(v_h - u_l) + v_l - (2 - \mu)c.$$

Then, we have $\pi^c - \widetilde{\pi}^d \equiv \mu u_l + (1 - \mu)c > 0$. Similarly, when the type-h buyers' static IC is binding, the firm's profit is given by

$$\widehat{\pi}^d \equiv 2\mu(v_h - u_h) + (1 - \mu)v_l + \mu u_l - (2 - \mu)c.$$

Then, we have $\pi^c - \widehat{\pi}^d \equiv \mu[2(u_h - u_l) - (v_h - v_l)] + \mu u_l + (1 - \mu)c > 0$ given the condition $2(u_h - u_l) > v_h - v_l$. So, introducing the damaged good is not profitable in either case. ■

[14] We assume that type-l consumers replace the damaged good to the original good even if they are indifferent.

Without the commitment role, the firm's incentive for quality degradation is smaller compared with the static case. Introducing the damaged good leads to more sales in the first period since it induces type-l consumers to buy the damaged good. Without the commitment role, however, it makes both the static and the intertemporal incentive constraints of type-h consumers more strict, and the effect of tighter incentive constraints dominates the additional sales effect. This result seems inconsistent with the stylised fact observed in the market for digitised information goods (such as computer software), where quality degradation is becoming quite a common practice. One possible explanation for the discrepancy may be that replacing software usually incurs buyers large switching costs, and so the market actually falls into the hardware regime ($v_l - u_l < c$). Or, it may be that quality degradation in software comes largely from other sources such as network externalities, as shown by Csorba (2002), Hahn (2002a,b) and Jing (2002).

4.3 The welfare effect of quality degradation

This subsection analyses the welfare implication of the profitable quality degradation in the non-commitment case. We focus on the case where the damaged good plays the commitment role, i.e. $v_l - u_l \leq c$. Otherwise, quality degradation is not profitable and the damaged good will not be observed. As usual, social welfare is defined as the sum of consumer surplus and profits. The equilibrium of the standard case without the damaged good yields total welfare of

$$W = 2\mu v_h + (1-\mu)v_l - c.$$

The total welfare with quality degradation is given by

$$W^d = 2\mu v_h + 2(1-\mu)u_l - c.$$

Then, the incremental welfare due to quality degradation is given by

$$\Delta W \equiv W^d - W = (1-\mu)(2u_l - v_l),$$

and the introduction of the damaged good increases social welfare if and only if

$$v_l < 2u_l. \tag{4}$$

The incremental welfare critically depends on how the type-l buyers' gross surplus changes according to the quality degradation, and in fact a welfare improvement requires that type-l buyers' gross surplus be larger when purchasing the damaged good in the first period rather than waiting and buying the original good in the second period. The welfare consequence of quality degradation then hinges on whether condition (4) is compatible with condition (3). We formalise the result in the following proposition.

Proposition 4 *Suppose that the damaged good plays the intertemporal commitment role (i.e. $v_l - u_l \leq c$). Then, for $R_o > R_d$ the profitable introduction of the damaged good always reduces welfare, and for $R_o < R_d$ it can be welfare-reducing, welfare-improving, and (weakly) Pareto-improving.*

Proof. Suppose that the introduction of the damaged good is profitable and increases welfare. Then, the compatibility of conditions (3) and (4) requires that

$$\frac{\mu u_h - u_l}{\mu v_h - v_l} < \frac{u_l}{v_l},$$

which under Assumption 1 reduces to

$$R_o = \frac{v_l}{v_h} < \frac{u_l}{u_h} = R_d. \tag{5}$$

So, the profitable introduction of the damaged good must be always welfare-reducing for the case of $R_o > R_d$, which contradicts condition (5). It is obvious from condition (5) that the profitable introduction of the damaged good can be compatible with welfare improvement for the case of $R_o < R_d$. Suppose that $v_h < 2u_h$. Then, the condition for introducing the damaged good to be profitable (condition (3)) guarantees a welfare improvement (condition (4) always holds). Also, given that $v_h < 2u_h$, a (weak) Pareto-improvement can be achieved if the incremental net surplus of a type-h buyer due to the introduction of the damaged good is positive, i.e.

$$2u_l - (2u_h - v_h) < v_l < 2u_l - \mu(2u_h - v_h).$$

The profitable introduction of the damaged good, however, leads to a welfare reduction if condition (3) holds but condition (4) does not, i.e.

$$2u_l < v_l < 2u_l + \mu(v_h - 2u_h),$$

which can be realised when $v_h > 2u_h$. ■

Note that a reduction of total welfare implies that type-h buyers become worse-off, since type-l buyers end up with zero net surplus anyway regardless of the presence of the damaged good.

5 Static vs Intertemporal

We have a clear result in the case where the damaged good fails to play the commitment role. The firm's incentive for quality degradation is certainly smaller in the intertemporal regime compared with the static regime. The comparison is more interesting in the other case where the damaged good plays the intertemporal commitment role. It will is useful to compare the equilibrium results in the two different regimes under the three typical cases of consumer preference structure.

- $R_o < \mu < R_d$: The monopolist has the incentive to introduce the damaged good in both the static and intertemporal regimes. The welfare effect of quality degradation, however, is much less promising in the intertemporal case relative to the static case: the introduction of the damaged good is always (weakly) Pareto-improving in the static setting, whereas it can leads to a welfare reduction in the intertemporal setting.

- $R_o < R_d \leq \mu$: Introducing the damaged good is never profitable to the static monopolist while it can be profitable if the commitment value of the damaged good is large enough to compensate the negative effect of price discrimination. The welfare consequence of quality degradation in the intertemporal regime is generally ambiguous: it may reduce or increase welfare, and even lead to a (weak) Pareto improvement.

- $R_d \leq R_o < \mu$: Similar to the previous case, only the intertemporal monopolist may have the incentive for quality degradation. However, the introduction of the damaged good always reduces social welfare. Note that this region accommodates the standard utility structure ($R_d = R_o$) as a special case.

Summarising the all the comparison results above, quality degradation is more likely to be employed by a durable-goods monopolist if it serves the intertemporal commitment role, but its welfare consequence is much less promising compared with the static setting.

6 Conclusion

This paper has shown that in a durable-goods market quality degradation can be used as a commitment not to lower price in the future. In such a case, quality degradation helps the firm to mitigate the Coasian time-inconsistency problem, and damaged goods are more likely to be observed relative to markets for non-durables. However, quality degradation is likely to be socially undesirable when it is motivated for the purpose of intertemporal commitment rather than the static price-discrimination. Low-valuation consumers are induced to consume the low-quality damaged good even if without the damaged good they could get larger gross surpluses by waiting and purchasing the high-quality original good. This is in striking contrast with the static case with non-durables, where the profitable introduction of the damaged good, even though it is less likely to occur, leads to a Pareto-improvement. Also, it has been pointed out that the intertemporal commitment role of the damaged good crucially depends on the significance of the marginal production cost relative to the early (low-valuation) buyers' willingness-to-pay for replacement, and quality degradation of information goods such as computer software is better to be explained by other sources (e.g. switching costs, network externalities, ...) other than the intertemporal commitment. I hope these results can provide a testable hypothesis for welfare implications of many durable and non-durable damaged goods observed in reality.

Our analysis is restricted to the simple two-type and two-period model. Nevertheless, the main insights of our results would carry over to more general environments. First, we may consider a continuous distribution of consumer type within the two-period framework. Again, the firm would introduce a damaged good in the first period (the sequential introduction is time-inconsistent). A typical equilibrium outcome would involve potential buyers being segmented in five groups: the upper high-valuation group who buy the original good in the first period, the lower high-valuation group who buy the original good in the second period, the upper low-valuation group who buy the damaged good in the first period, the medium low-valuation group who buy the damaged good in the second period, and finally the bottom low-valuation group who buy nothing. The firm's optimal pricing strategy will be chosen to ensure the presence of the lower high-valuation group (for there would be no commitment value of quality degradation without it), and also to discourage the upper low-valuation group's replacement demands. We could derive the conditions for introducing the damaged good to be profitable, but the complications come in the welfare analysis and its comparison with the static case. However, we can expect there will be at least a partial commitment role of quality degradation to future prices and thereby helping the firm to mitigate the time-consistency problem, and in such a case the welfare effect would be less promising due to the surplus losses of the early buyers of the damaged good. An extension to an infinite-horizon would also yield similar results. Without quality degradation, the typical Coase outcome will appear (the monopolist loses his monopoly power completely) as the length of time between the price adjustments tends to zero. Introducing a damaged good at some point of time will increase the firm's profit by preventing the price for the original good from dropping to its lowest possible level. Finally, it would be interesting to consider the possibility of technological innovation (or new product introduction) together with quality degradation, and investigate the interaction between downgrades and upgrades in a unified framework. Ambjørnsen, T. (2002b) takes a first step towards this direction.

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