Market Structure and the Incentive to Practice Economic Obsolescence*

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Abstract

This paper examines the decisions of a durable goods monopolist concerning new product introductions in the presence of technological progress. We show that the incentive for a monopolist to introduce a new product is lower than the social optimum. However, it is too high from the viewpoint of the monopolist's own profitability if the monopolist is unable to commit to economic durability. We also show that competition from new product introductions reduces economic durability and may lead to socially excessive economic obsolescence.

1. Introduction

Most of the literature related to the durability choice problem assumes that a good's durability is equal to its "physical" lifetime, and concludes that durable goods monopolists build less than the socially optimal level of physical durability into their products; that is, they practice planned obsolescence (e. g., see Coase (1972), Bulow (1982, 1986) and Bond and Samuelson (1984)). It is assumed that consumers continue to possess a good until it breaks down in their papers. However, when technological progress occurs, a manufacturer can introduce a new product that makes consumers want to replace the old units that they own. For example, automobile manufacturers may have an incentive to introduce style changes, PC manufacturers frequently introduce personal computers with an upgraded CPU, and publishers of computer software routinely introduce updated programs.[1] It is often observed that, with a frictional second-hand market, a good's "economic durability", the length of time between its purchase by a consumer and its replacement by a newer one, is shorter than its "physical durability." This phenomenon is referred to as "economic obsolescence"[2]. The literature to date has given little attention to such an obsolescence mechanism.

We construct a continuous-time and infinite-period model of a durable goods monopoly in the presence of technological progress, and investigate the durable goods monopolist's incentive to introduce a new product. When a consumer already possesses an old product, the

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monopolist's ability to extract consumer surplus from the new product is constrained by the reservation value of possessing the old product; that is, the "reservation utility effect" works. We show that the monopolist's incentive to introduce a new product is less than the social optimum because of the reservation utility effect. Accordingly, the monopolist chooses a level of economic durability that is above the socially optimal level. This contrasts with the traditional result concerning planned obsolescence of physical durability. It is also shown that the incentive for a monopolist to introduce a new product is too high from the viewpoint of the monopolist's own profitability because of a time inconsistency problem concerning the introduction of a new product when the monopolist is unable to commit to economic durability. Thus, the time inconsistency effect reduces economic durability and hurts the monopolist. We also investigate the effect that competition from product introductions has on the firms' choice of economic durability. Whether the economic durability level that competitive firms choose is longer than the socially optimal level depends on parameter sets. Competition from new product introductions may reduce economic durability wastefully.

Waldman (1993) and Choi (1994) use a two-period model and show that the durable goods monopolist has too high an incentive to introduce a new product in the presence of network externality. In their papers, the distortion is caused only by the presence of network externality. In our model, the presence of the reservation utility effect reduces the private incentive to introduce a new product. Waldman (1996) demonstrates that the durable goods monopolist who faces the time inconsistency problem concerning the R&D decision over-invests in R&D from the standpoint of the monopolist's own profitability. His result concerning the time inconsistency problem is analogous to ours. However, with regard to social welfare consequences, Waldman's result is different from ours. Waldman assumes that there is an uncertainty about whether the R&D investment will be successful. This uncertainty reduces the effect of the R&D investment for social welfare improvement. Since the present paper assumes that potential technology, which is continuously developed, is exogenously given, such a welfare loss does not occur. Another related paper is Lee and Lee (1998). They characterize the magnitude of innovation costs such that economic obsolescence occurs by using a two-period model of a durable goods monopoly. However, they focus on economic obsolescence caused by a monopolist's upgrade policy, and their result depends on the assumptions of a two-period model. We present a continuous-time and infinite-period model, and investigate the timing of new product introductions in the cases of a monopoly and a competitive market. Furthermore, we analyze the effects of a frictional second-hand market, a time inconsistency problem and competition of product introductions on economic durability.[3)]

The outline of the paper is as follows: Section 2 provides our basic model of a durable goods monopoly in the presence of technological progress. Section 3 investigates the incentive for a monopolist to introduce a new product. Section 4 discusses the time inconsistency problem concerning the introduction of a new product, and also compares the monopoly equilibria with the social optimum. Section 5 extends the monopoly case to a competition case and examines the effect that competition from product introductions has on economic durability. Section 6 presents our conclusion.

2. The Model

We consider a continuous-time and infinite-period setting with a monopolist who produces and sells durable goods. In section 5, we will extend our setting to a competitive market case. The monopolist's output is assumed to provide a constant flow of services for infinite periods. That is, the product undergoes no physical depreciation. We also assume that potential technology, which is continuously developed, is exogenously given. More advanced technology produces a product of higher quality. The monopolist invests in converting the state-of-the-art technology into actual production. That is, the monopolist chooses the timing of new product introductions. We call the product of the τth introduction as the generation τ product, $\tau=1,2,\ldots$. We denote quality of the generation τ product by v_τ. Converting potential technology into actual production and introducing the generation τ product requires investment costs kv_τ ($k\geq 0$ is a constant). Without loss of generality, costs of production are assumed to be zero.

Consumers are homogeneous and live for infinite periods. Each consumer consumes either zero or one unit of the monopolist's output. The consumer population N is assumed to be fixed. We assume that each consumer derives a flow utility v_τ from the consumption of quality v_τ. We also assume that a consumer who purchases a new product can dispose of the old unit that he or she owns at no cost. The monopolist and all consumers have a common discount rate r. The values of all parameters are common knowledge.

We denote the length of time between the introductions of the generation τ product and the generation $\tau+1$ product by $L_\tau>0$. The introduction of a new product inevitably makes all consumers, who are assumed to be homogeneous, replace the old product that they own with a newer one. The assumption of homogenous consumers also eliminates the second-hand market. Therefore, economic durability can be interpreted as the length of time between the dates of the introduction of a new product and the introduction of the next product. Thus, we can interpret L_τ as a proxy representing the "economic durability" of the generation τ product.

We will derive the generation τ product's price p_τ. We begin by examining the consumer's incentive constraint after the generation $\tau-1$ product was already introduced ($\tau=2,3,\ldots$). When the monopolist introduces the generation τ product into the market, a consumer who already possesses the generation $\tau-1$ product has two options:

[Option A] replace the generation $\tau-1$ product with the generation τ product; and

[Option B] continue to possess the generation $\tau-1$ product.

Under the assumption of homogeneous consumers, a second-hand market does not exist. Therefore, [Option A] implies that the consumer disposes of the generation $\tau-1$ product and purchases the generation τ product from the monopolist. New product introductions do not make existing products physically obsolete. Economic obsolescence occurs only when consumers choose [Option A][4]. Then, the monopolist is able to charge the price for the new product that makes consumers choose [Option A]. That is, the monopolist can practice economic obsolescence. Since consumers expect the monopolist's behaviour, the expected utility they are able to obtain from the new product equals to the discounted value of the benefit the new product yields for its economic durability. Thus, the incentive constraint of the consumer who prefers [Option A] to [Option B] is

$$v_t\int_0^{L\tau} e^{-rt}dt - p_\tau \geq \frac{v_{\tau-1}}{r} \tag{1}$$

The left-hand side of (1) represents a consumer's benefit from accepting economic obsolescence, and the right-hand side represents his or her benefit from rejecting it. Since the monopolist charges the maximum price that satisfies constraint (1), the generation τ product's price is

$$p_\tau = \frac{v_\tau}{r}(1-e^{-rL_\tau}) - \frac{v_{\tau-1}}{r} \tag{2}$$

When a consumer already possesses an old product, the monopolist's ability to extract consumer surplus from the new product is constrained because of the "reservation utility effect". In other words, such a monopolist must offer a new product's price discounted of the reservation value of possessing the old product.[5)]

Next, we examine the consumer's incentive constraint at date 0. The consumer who purchases the first-generation product expects that the monopolist will introduce the new product at date L_1 and this makes the consumer choose [Option A]; that is, the monopolist's introduction of the second-generation product makes the first-generation product economically obsolete. Since the consumer receives utility from the consumption between date 0 and date L_1, he or she purchases the first-generation product if

$$v_1\int_0^{L1} e^{-rt}dt - p_1 \geq 0. \tag{3}$$

What differs from constraint (1) is that the consumer who purchases the first-generation product does not possess any product. Since the monopolist charges the maximum price that satisfies constraint (3), the first generation ($\tau=1$) product's price is

$$p_1 = \frac{v_1}{r}(1-e^{-rL_1}).$$

The price formation depends on two assumptions related to the demand structure described in this paper. First, since each consumer is assumed to have at most one unit of demand, a consumer who has purchased a new product cannot enjoy the old product simultaneously. For instance, a person cannot drive two cars at the same time.[6)] Second, the assumption of homogeneous consumers precludes the complications of the price formation in the second-hand market. As long as there is a complete second-hand market, all products would live out their physical lifetime. However, in the real world, complete second-hand markets rarely exist, owing to asymmetric information, transaction costs, and so on.[7)] Therefore, consumers scrap products even before the products break down. Thus, economic obsolescence will occur. The simplest way to model economic obsolescence is to adopt the assumption of homogeneous consumers. Relaxing this assumption would not alter this paper's results substantially.

In order to restrict attention to a stationary subgame perfect Nash equilibrium, we assume that technological progress takes the form

$$v_\tau=\lambda\theta^t,\ t=\sum_{i=1}^{\tau-1}L_i,\ \lambda>0 \text{ and } \ln\theta\in(0,r), \tag{4}$$

The parameter λ is a constant and represents the utility of the initial technology, and the parameter θ measures the rate of potential technological progress. The restriction on the parameter $\ln\theta\in(0,r)$ ensures that the present discounted value of the monopolist's profits has an upper bound. Assumption (4) guarantees that whenever the monopolist introduces a new product, it always faces the identical discounted value of the profit stream irrespective of the product's generation. Therefore, we can find the unique stationary economic durability.[8)]

3. The Monopolist's Choice of Economic Durability

We will analyze the monopolist's choice of economic durability. The monopolist who is unable to commit to economic durability faces a time inconsistency problem concerning the introduction of a new product. That is, the monopolist chooses the date of the introduction of a new product so as to maximize current profitability rather than overall profitability. After the monopolist has sold the generation τ product, the monopolist has to decide the date of the introduction of the next generation product (the generation $\tau+1$ product). Note that the decision on the introduction date of the generation $\tau+1$ product is equivalent to the decision on economic durability of the generation τ product. The monopolist faces the problem of deciding whether to introduce a new product and extract current consumer surplus or to adopt a strategy that delays the new product's introduction and extract a higher, although later, surplus. Delaying the introduction of the new product causes the monopolist the loss of current profit. On the other hand, it increases the new product's price because of the improvements in quality, and saves the costs of adopting the new technology. The following proposition characterizes the monopolist's choice of economic durability when the monopolist is unable to commit to economic durability.

Proposition 1: Suppose that the durable goods monopolist is unable to commit to economic durability. The monopolist chooses a level of economic durability that is less than the level of physical durability in a stationary equilibrium.

Proof: Suppose that a monopolist sells the generation τ product at any date t $(t=\sum_{i=1}^{\tau-1}L_i)$. The problem for the monopolist is to decide the date of the introduction of the $\tau+1$ generation product. When the monopolist chooses a stationary economic durability L, the present discounted value of the profit stream from date $t+L$ is given by

$$\mu(L)=\sum_{s=1}^{\infty}e^{-r(s-1)L}[NP_{\tau+s}(L)-kv_{\tau+s}(L)]. \tag{5}$$

Substituting the price path (2) into the function (5) and using assumption (4) yields

$$\mu(L)=\frac{N\lambda\theta^t}{r}\left[\frac{\theta^L(\alpha-e^{-rL})-1}{1-\theta^L e^{-rL}}\right],$$

where $\alpha\equiv 1-(rk/N)$. To simplify the expression, we define

$$\phi(L)\equiv\frac{\theta^L(\alpha-e^{-rL})-1}{1-\theta^L e^{-rL}}, \tag{6}$$

We define the function $\Psi(x)$ as follows:

$$\Psi(x)\equiv\begin{cases}\dfrac{N\lambda\theta^t}{r}\left[e^{r(L^M-x)}\phi(x)-\phi(L^M)\right] & if\ 0<x\leq L^M\\ \dfrac{N\lambda\theta^t}{r}\left[e^{-r(x-L^M)}\phi(x)-\phi(L^M)\right] & if\ L^M<x\end{cases}$$

where L^M represents the equilibrium level of economic durability when the monopolist is unable to commit to economic durability. The variable x denotes the level of economic durability in the case where the monopolist uses the deviation strategy. Note that $\Psi(L^M)=0$. As long as the function $\Psi(x)$ is positive, the monopolist has an incentive to deviate from L^M to x. Since the function $\Psi(x)$ must attain the maximum at L^M, the equilibrium condition is given by $\Psi'(L^M)=0$; i. e.,

$$\phi'(L^M)-r\phi(L^M)=0 \tag{7}$$

Substituting definition (6) into condition (7), L^M is given by a unique solution to

$$r(1-\theta^{2L}e^{-2rL})-(r-\ln\theta)\theta^L(\alpha-2e^{-rL})=0. \tag{8}$$

The second-order condition is satisfied. Since the choice of L^M does not depend on t, the stationary equilibrium is supported. Q. E. D.

We now examine how changes in the rate of technological progress affect the monopolist's choice of economic durability.

Proposition 2: An increase in the rate of technological progress advances the introduction of a new product.

Proof: From equation (8) we obtain

$$\frac{dL^M}{d\theta}=\frac{G(L^M)}{F(L^M)},$$

where

$$F(L^M)=-2r(r-\ln\theta)\theta^{LM}e^{-rLM}(1-\theta^{LM}e^{-rLM})-\ln\theta(r-\ln\theta)\theta^{LM}(\alpha-2e^{-rLM})$$

and

$$G(L^M)=\theta^{LM-1}\left[2rL^M\theta^{LM}e^{-2rLM}+((r-\ln\theta)L^M-1)(\alpha-2e^{-rLM})\right].$$

Using condition (8) yields

$$F(L^M)=-2r(r-\ln\theta)\theta^{LM}e^{-rLM}(1-\theta^{LM}e^{-rLM})-r\ln\theta(1-\theta^{2LM}e^{-2rLM})<0.$$

Using condition (8) also yields

$$G(L^M)=\frac{r}{\theta}\left[2L^M\theta^{2L^M}e^{-2rL^M}+\frac{((r-\ln\theta)L^M-1)(1-\theta^{2L^M}e^{-2rL^M})}{r-\ln\theta}\right]$$
$$=\frac{r(1+\theta^{2L^M}e^{-2rL^M})}{\theta(r-\ln\theta)}\xi(L^M).$$

where $\xi(L)\equiv L(r-\ln\theta)-(1-\theta^{2L}e^{-2rL})/(1+\theta^{2L}e^{-2rL})$. Since $\xi'(L)>0$ for all $L>0$ and $\xi(0)=0$, $\xi(L)>0$ holds for all $L>0$. Therefore, the sign of $G(L^M)$ is positive. Thus, we obtain the result that $dL^M/d\theta<0$. Q. E. D.

Proposition 2 explains why products in some industries are replaced more often than those in other industries. An increase in the rate of technological progress increases the consumers' willingness to pay for a new product, thus intensifying the monopolist's incentive to introduce a new product. For example, there has been little technological progress related to radios and refrigerators, and so they are seldom replaced with new models. On the other hand, personal computers and video games, where the rate of technological progress is high, will be replaced frequently.

4. Time Inconsistency and Socially Optimal Economic Durability

First, this section will compare the monopoly equilibrium in the commitment case with that in the non-commitment case. The comparison is useful for examining how the lack of the commitment distorts the monopoly equilibrium from the standpoint of the monopolist's overall profitability. The non-commitment solution L^M does not maximize the monopolist's overall profits, since the monopolist who is unable to commit faces a time inconsistency problem concerning the introduction of a new product. Let L^C denote the equilibrium level of economic durability in the commitment case.

Proposition 3: A durable goods monopolist who is unable to commit to future economic durability chooses a lower level of economic durability than the monopolist would under the commitment case.

Proof: Suppose the monopolist is able to commit to economic durability. When the monopolist chooses a stationary economic durability, the monopolist's overall profits is given by

$$\Pi(L)=\sum_{s=1}^{\infty}e^{-r(s-1)}[Np_s(L)-kv_s(L\}]$$
$$=\frac{N\lambda}{r}[(\alpha-e^{-rL})+e^{-rL}\phi(L)].$$

The first-order condition for profit maximization yields

$$r+[\phi'(L^C)-r\phi(L^C)]=0 \tag{9}$$

The second-order condition is satisfied. Condition (9) implies that

$$\phi'(L^C)-r\phi(L^C)<0. \tag{10}$$

Comparing equation (10) with the equilibrium condition (7) yields $L^C>L^M$. Q. E. D.

A monopolist who is unable to commit to economic durability faces a time inconsistency problem concerning the introduction of a new product (that is, the choice of economic durability). Consider the first-generation product. An increase in economic durability of the first-generation product increases the first-period price. A monopolist who is unable to commit, however, does not internalize this increase in the first-period price when deciding the economic durability of the first-generation product. Similarly, in the choice of economic durability of the generation $\tau(\geq 2)$ product, the monopolist again faces the time inconsistency problem. Consequently, the monopolist's incentive to introduce a new product is too high from the standpoint of the monopolist's own profitability.

In the remainder of this section, we will examine the socially optimal level of economic durability. The purpose of a social planner is to maximize social surplus. We assume that the social planner chooses a stationary economic durability. Social surplus, that is, consumer surplus minus adoption costs of new technology, is given by

$$W(L)=\frac{N\lambda}{r}(\alpha-e^{-rL})\sum_{s=1}^{\infty}\theta^{(s-1)L}e^{-r(s-1)L}. \tag{11}$$

The following proposition compares the monopoly equilibria in the commitment and no-commitment cases with the social optimum. Below L^* denotes the socially optimal level of economic durability.

Proposition 4: The durable goods monopolist chooses a level of economic durability that is above the socially optimal level, irrespective of whether the monopolist is able to commit to economic durability or not.

Proof: Social surplus (11) is rewritten as

$$\begin{aligned}W(L)&=\Pi(L)+\frac{N\lambda}{r}\sum_{s=1}^{\infty}\theta^{(s-1)L}e^{-rsL}\\&=\Pi(L)+\frac{N\lambda}{r}\eta(L),\end{aligned}$$

where $\eta(L)\equiv e^{-rL}/(1-\theta^L e^{-rL})$. Social surplus is larger than the monopolist's overall profits by the present discounted value of the reservation utility. The first-order condition for social surplus maximization is given by

$$\phi'(L^*)-r\phi(L^*)+r+\eta'(L^*)=0. \tag{12}$$

The second-order condition is satisfied. It is straightforward to show that $\eta'(L)<0$ and $(r+\eta'(L))<0$ for all L. Since $(r+\eta'(L))$ is negative, condition (12) implies that

$$\phi'(L^*)-r\phi(L^*)>0. \tag{13}$$

Comparing equation (13) with the equilibrium condition (7) yields $L^*<L^M$. It is clear that $L^*<L^C$, since $L^C>L^M$ from proposition 3. Q. E. D

Figure 1 depicts the monopolist's overall profits and social surplus. Recall that L^C maximizes the monopolist's overall profits, L^* maximizes social surplus and L^M falls between L^* and L^C. The reasoning behind proposition 4 is as follows. First, the monopolist's ability to extract consumer surplus from the new product is constrained because of the reservation utility effect. The present discounted value of the reservation utility constitutes consumer surplus $(N\lambda/r)\eta(L)$, which is a decreasing function in economic durability L. The monopolist does not consider the effect that the level of economic durability has on consumer surplus when choosing the level of economic durability. Thus, the left hand of condition (9) is larger than that of condition (12) by $|\eta'(L)|$. This means that the monopolist has an incentive to increase economic durability. Such an increase in economic durability increases the new product's price. Next, we compare condition (7) with condition (12). The left hand of condition (7) is larger than that of condition (12) by $|r+\eta'(L)|$. In the non-commitment case, the reservation utility effect weakens the monopolist's incentive to introduce a new product, whereas the time inconsistency effect intensifies it. The former effect unambiguously dominates the latter since $(r+\eta'(L))<0$ for all L. Thus, irrespective of whether the monopolist is able to commit to economic durability or not, the monopolist's incentive to introduce a new product is too low from the standpoint of social welfare. That is, the level of economic durability that the monopolist chooses is above the socially optimal level.

5. Competition of New Product Introductions

We will consider firms that competitively introduce new products and analyze the effect that competition from new product introductions has on the determination of economic durability. Assume that there are n firms that have identical technology. Firms enter into this market if they find it profitable to introduce a new product. If firms simultaneously introduce an identical new product, then they have an equal share. Thus, the firm h's $(h=1,\dots,n)$ profits when introducing the generation τ product are given by

$$\pi_{\tau,h}=\frac{N}{n}\left[\frac{v_\tau}{r}(\alpha-e^{-rL\tau})-\frac{v_{\tau-1}}{r}\right].$$

By using assumption (4), we derive a stationary competitive equilibrium. A competitive level of economic durability has to satisfy the zero profits condition;

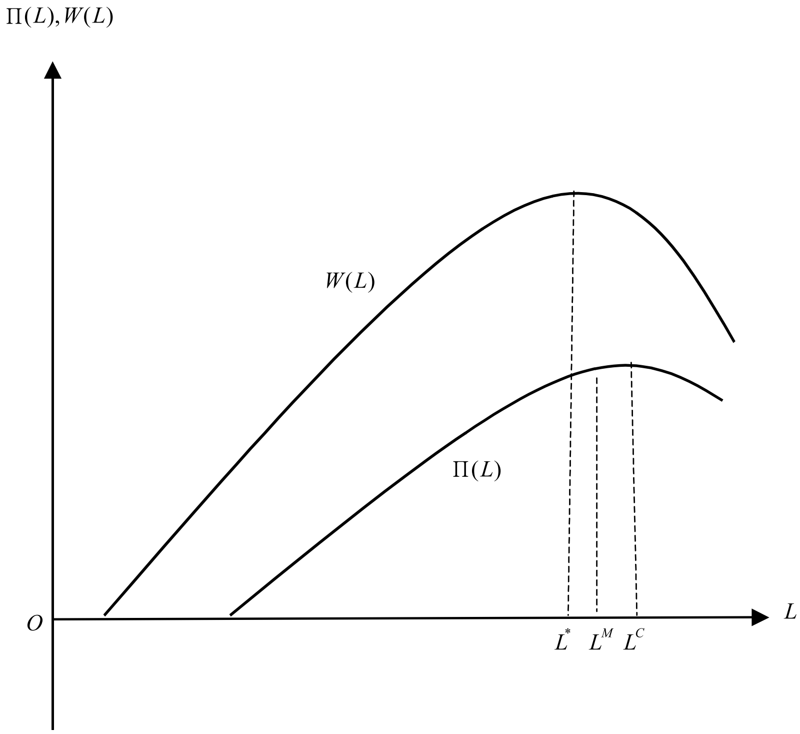
$$\theta^{LCOM}(\alpha-e^{-rLCOM})-1=0. \tag{14}$$

The following proposition examines the relationship between L^{COM} and L^M.

Proposition 5: The level of economic durability chosen by a firm that competitively introduces new products is not larger than what the monopolist would choose, i. e., $L^{COM}\leq L^M$.

Proof: Since competition makes each firm's profits zero, L^{COM} is not larger than any L such that $\Pi(L)\geq 0$. Therefore, $\Pi(L^M)\geq 0$ implies that $L^{COM}\leq L^M$. Q. E. D.

Proposition 5 states that competition from new product introductions reduces economic durability. That is, it hastens economic obsolescence. Figure 1 depicts the relationship between L^{COM} and L^{M}. Proposition 5 contrasts with Bulow's (1986) result concerning physical durability. Bulow shows that a competitive firm chooses a higher level of physical durability than the monopolist would.



Lastly, the relationship between L^{COM} and L^{*} will be examined. The relationship depends on parameters and the calculation is complicated. By evaluating the first-order derivative of social surplus with respect to L at $L=L^{COM}$, the relationship between L^{COM} and L^{*} will be found. If $W'(L^{COM}) \geq (<) 0$, then $L^{COM} \leq (>) L^{*}$. Combining conditions (12) and (14) yields the following condition:

$$W'(L^{COM}) \gtreqless 0 \quad \Leftrightarrow \quad \omega(L^{COM}) \gtreqless 0, \tag{15}$$

where $\omega(L) \equiv \ln\theta - r\theta^{L}e^{-rL}$. Therefore, $L^{COM} \leq (>) L^{*}$ when $\omega(L^{COM}) \geq (<) 0$. The sign of $\omega(L^{COM})$ depends on parameters. Thus, competition from new product introductions may reduce economic durability wastefully.

6. Conclusion

A familiar result in the literature related to durable goods markets is that a monopoly seller builds less than the socially optimal level of "physical durability" into its output. This paper has investigated the monopolist's incentive for obsolescence of a good's "economic durability." In the presence of technological progress, the monopolist's incentive to introduce a new product is too large from the standpoint of the monopolist's overall profitability. This is caused by the time inconsistency problem concerning the introduction of a new product. However, the monopolist's incentive to introduce a new product is too low from the standpoint of social welfare. That is, the monopolist chooses a level of economic durability that is above the socially optimal level. This result holds irrespective of whether the monopolist is able to commit to economic durability or not. It has been also shown that competition of product introductions reduces economic durability. Therefore, competition may lead to socially excessive economic obsolescence.

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Notes

1) Galbraith (1958) suggests that the annual model changes of automobile manufacturers are socially wasteful.
2) If there were a complete second-hand market, all goods would live out their physical lifetime. However, in the real world, the second-hand market has some friction.
3) Fishman, Gandal and Shy (1993) and Shy (1996a) uses an overlapping generations model to show that excessive durability may arrest technological progress in a competitive market. Their results largely depend on the structure of cost function. Shy (1996b) also investigates the demand side factor affecting the adoption of new technology.
4) For example, the appearance of personal computers with an upgraded CPU does not necessarily destroy utility for old-product users, although it often kills off the second-hand market for old machines.
5) The reservation utility effect prevents a durable goods monopolist from extracting consumer surplus. It is shown that this effect distorts the monopolist's choice from the social optimum in various models of a durable goods monopoly (e. g., see Fishman, Gandal and Shy (1993), Waldman (1993), Choi (1994), Fudenberg and Tirole (1998), Kinokuni (1999)).
6) A person may own two cars, for business and pleasure. In order to incorporate such a consumer into this paper's model, it is necessary to generalize consumer preference further.
7) Akerlof (1970), in his classic discussion of lemons, shows that asymmetric information concerning product quality leads to thin markets for used cars. In this paper's model, used goods markets are excluded by assumption.
8) Shy (1996b) uses a similar technology function to analyze the non-durable goods firms' technology adoption in the presence of network externality.