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Secondary markets with changing preferences

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If consumer valuations change over time, then secondary-market frictions may raise monopoly profits and cause durability to be distorted away from the cost-minimizing level. A monopolist who favors such frictions overinvests in durability, but planned obsolescence instead may be preferred when market frictions exist but a monopolist wishes they did not. Evidence from the book market is presented.

1. Introduction

■ In this article I examine secondary markets with trade frictions, under the assumption that secondary trade is motivated by idiosyncratic changes in consumer preferences over time.[1] For example, the house or car that is appropriate today may not be in the future due to changes in family status, wealth, or location. Similarly, one's hobbies (and hence purchases) or taste for music, books, art, or clothes may vary over time (one's ability to fit into certain clothes may also change).[2]

The motivation for trade considered in my analysis is similar to mechanisms investigated by others in previous work, including in the empirical industrial organization literature in which it is common to assume that preferences shift over time.[3] Thus, my contribution is not to suggest a novel motivation for trade but instead to assess how firms with market power might gain from constraints on secondary markets when trade is driven by changing preferences. I consider transaction costs for trading used units, and also durability manipulation, as ways in which the secondary market may be influenced.

I present two main results for a durable-goods monopolist with commitment power selling to consumers with changing valuations. First, secondary-market frictions facilitate a type of price

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[1] In contrast, much of the existing theoretical literature on secondary-market interference, such as Anderson and Ginsburgh (1994), Waldman (1996a), and Hendel and Lizzeri (1999), assumes that trade is driven by differences in the marginal valuations for quality among consumers.

[2] Bulow (1982) offers baby carriages as a potential product for which individual demand may change.

[3] See, for example, House and Leahy (2004) and House and Ozdenoren (2008), who consider changes in the match values between consumers and products as I do, Grossman and Laroque (1990) and Eberly (1994), who consider how wealth changes influence product holdings, Biehl (2001), who considers leasing and selling when consumer preferences change, Jovanovic (1979), who considers learning about the value of a match over time in the labor market context, and Chen, Esteban, and Shum (2010), who empirically consider the used car market with changing consumer preferences.

discrimination that may but need not raise profitability. Second, such market frictions lead to a distortion of durability away from the level that minimizes costs. It may be optimal to design products that die excessively quickly (planned obsolescence) or instead ones that last excessively long (planned durability); which is optimal depends on the monopolist's preferences for frictions.

My first result (that a monopolist may prefer market frictions) differs from the lessons of the existing literature. Swan (1980) famously reasoned that because the price a monopolist receives from the sale of a new unit includes its potential resale value it must be the case that secondary markets place no constraint on profitability. Rust (1986) and Hendel and Lizzeri (1999) also conclude that a monopolist prefers smoothly functioning secondary markets.[4]

The reason that the logic of Swan may fail is that it overlooks that transaction costs can help the monopolist better segment the market. An intuition is as follows. When preferences change over time, a consumer who buys a unit today may have a sufficiently low valuation tomorrow that he would resell the unit save for the presence of transaction costs. This means that transaction costs permit the monopolist to keep (used) units in the hands of additional lower-valuation consumers, without having to lower the market price to those consumers' valuations. Furthermore, because the monopolist is always free to increase future production to temper the static inefficiency caused by heightened frictions, the net effect may be to increase the number of consumers holding units.[5]

A recent example in which it seems firms (at least currently) prefer trade frictions is provided by the market for electronic books. Two popular electronic-book readers, the Nook and the Kindle, use digital rights management software to prevent permanent trading of electronic books. I return to this example in Section 5.

My second result (that a monopolist may either underinvest or overinvest in durability relative to the cost-minimizing level) is surprising in light of the famous Independence Result articulated in Swan (1970, 1971, 1972) and Sieper and Swan (1973), which says that a monopolist will choose durability to minimize costs.[6] In Swan's analysis, markets are frictionless and so durability as such does not influence which consumers hold units—the consumers with the highest current valuations always hold all available units. As such, durability only influences costs, given the marginal consumers.

The reason that Swan's result need not hold more generally is that the presence of secondary-market frictions breaks the substitutability of old and new units; with frictions, a used unit is different from a new unit because a new unit will always be held by a consumer with a high current valuation whereas a used unit need not be. Consequently, with market frictions, durability changes directly influence which consumers hold units and hence both revenue and costs are influenced, leading to durability levels that need not minimize costs.

Although the details of the durability decision are somewhat complex, there is a strong qualitative conclusion. When frictions are preferred, they complement durability and overinvestment occurs. However, when smoothly functioning secondary markets are preferred but frictions actually exist, frictions and durability are substitutes and underinvestment occurs.

Although Swan's Independence Result is likely the most well known statement regarding a monopolist's incentives to invest in durability, other researchers have certainly addressed the issue. Rust (1986) shows as I do that a monopolist may either underinvest or overinvest in durability.[7] Unlike his result, mine is driven by the desire of a firm to use durability as a tool

[4] Anderson and Ginsburgh (1994), in a framework similar to that of Hendel and Lizzeri (1999), show that a monopolist may prefer closed secondary markets. However, as noted by Hendel and Lizzeri, Anderson and Ginsburgh exogenously fix the durability of units, whereas a monopolist who can choose the durability prefers frictionless markets. The preference of a monopolist for frictions in my model can exist whether durability is exogenous or endogenous.

[5] See Chen, Esteban, and Shum (2010) for empirical work providing some evidence consistent with the possibility that producers may gain from market frictions.

[6] Strictly speaking, the Independence Result is that a monopolist would choose the same level of durability as a social planner, but in Swan's models this follows from the cost-minimization result.

[7] Also see Schmalensee (1979) for a review of circumstances in which Swan's result may break down. One such circumstance is in the transaction-costs analysis of Parks (1974). However, in his analysis, the transaction costs are those associated with buying new units and the analysis and intuition are unlike those presented here.

to price discriminate (consumers are homogeneous in Rust's analysis so that there can be no such discrimination). Additionally, in his model, durability distortions arise even with frictionless secondary markets (and indeed the firm does not gain from positive market frictions), whereas in my model when markets are frictionless there is no durability distortion. The reason is that in my model durability choice interacts with the basic price discrimination role of market frictions discussed above, so that when there are no trade frictions there is no reason to distort durability.

In contrast to my analysis, Waldman (1996a) and Hendel and Lizzeri (1999) define durability as the quality of used units as opposed to the probability that they survive to later periods, so that the presence of both new and used units on the market provides an opportunity to price discriminate along the lines of Mussa and Rosen (1978). As in that standard quality-discrimination framework, it may be optimal to distort the quality of (lower-quality) used units. These distortions arise when markets are frictionless, unlike in my analysis, and moreover the monopolist prefers frictionless markets, also unlike in my analysis.

The reason a monopolist prefers frictionless markets in the work of Waldman and Hendel and Lizzeri but not in mine is as follows. Quality discrimination requires that lower-quality units be held by those consumers with weaker preferences for quality. Because high-quality units become low-quality units over time in these analyses, achieving price discrimination is facilitated by frictionless trade because it ensures that more units are traded. In contrast, the price discrimination in my model, and hence incentives to manipulate durability, is predicated on preventing such trade so that consumers continue to hold units rather than trading them away.

There are also a number of articles that consider how a monopolist's inability to commit may influence its decisions. Bulow (1986) explains that low durability may restore the market power of a firm that cannot commit to future prices, whereas Waldman (1993) and Fudenberg and Tirole (1998) examine new product introductions. Waldman (1997) examines leasing-only policies. The main difference is that in my model the firm has no commitment problem, and hence the motivation for durability manipulation is very different.

I close by returning to the idea that a monopolist may gain by inducing secondary-market frictions. Although the previous literature on durable goods has suggested that frictionless markets are always preferred, there are several analyses that capture the spirit of the effect I identify although they are not framed in terms of trade on secondary markets. For example, Che (1996) explores return policies in the case of experience goods and shows that such policies are sometimes optimal but sometimes not; restricting the ability to return goods may be profitable if many consumers who would otherwise return the good have valuations exceeding the cost of production. This is similar to one of my results, which is that low costs of production make it more likely that a firm will prefer market frictions. Crémer (1984) shows that offering discounts for repeat purchases may be optimal for a monopolist, which is similar to the idea that transaction costs may induce more consumption by making keeping a unit preferable. Biehl (2001) shows that a monopolist may prefer to sell rather than lease when consumer preferences change over time. Lewis and Sappington (1994) and Johnson and Myatt (2006) explore a variety of situations in which a firm may wish to manipulate the information available to consumers where one factor at work is price discrimination that is similar to that identified in the present analysis. Paredes (2006) is somewhat related in identifying learning as a source of brand loyalty, an issue also present in Johnson (2005), whereas Gavazza (2011) considers random preferences in the secondary market for aircraft.

The remainder of this article is structured as follows. Section 2 contains the model. Section 3 contains analysis with a focus on comparative statics on market frictions. Section 4 introduces the product durability choice, and Sections 5 and 6 contain extensions.

2. A model of durable goods and preference changes

■ Consider the following two-period monopoly model of durable goods and secondary trade with changing preferences. In period one a monopolist sells q_1 indivisible products at constant marginal cost $c(\alpha)$, where $\alpha \in (0, 1)$ is a measure of durability that (for now) is exogenously given, and $c(\alpha)$ is increasing and convex. A product sold in the first period survives to provide benefits in the second period with probability α, and otherwise disappears. A surviving used good provides the same flow benefit to consumers as a new unit. No unit provides utility after the end of the second period.

In addition to selecting q_1 in period one, the firm commits to second-period output q_2, where q_2 is allowed to be negative to capture the idea that the firm may choose to buy back units at the prevailing market price in period two. If production is positive each unit has marginal cost c_2, which is also taken to be the scrap value of units that are bought back.[8] I focus on the commitment case to abstract away from the well-studied role of time inconsistency.

Let p_1 and p_2 denote the prices of units in periods one and two, respectively. Because there is no difference in the flow utility provided by a used unit versus a new one, p_2 is the price of either a new or a used unit in period two, and profits are

$$\Pi(q_1, q_2, \alpha) = q_1(p_1 - c(\alpha)) + \beta q_2(p_2 - c_2),$$

where β is the discount factor shared by the firm and consumers.

The demand side of the market is characterized by a unit mass of consumers with unit demands, whose per-period valuations change randomly. Consumers are initially indexed by their valuations for the product in the first period, $\theta_1 \in [0, \bar{\theta}]$, where θ_1 is distributed according to $F_1(\theta_1)$. A consumer of first-period valuation θ_1 has a second-period valuation $\theta_2 \in [0, \bar{\theta}]$ that is randomly realized at the beginning of period two according to the distribution function $F_2(\theta_2 \mid \theta_1)$ with marginal distribution $F_2(\theta_2)$. Once realized, these valuations are privately known to the consumers. The second-period distribution functions are ranked by θ_1 in terms of first-order stochastic dominance, which will imply (given the rest of the model) that exactly those consumers with sufficiently high first-period valuations buy in period one. Consumers have an outside option of zero.

This formulation admits the prospect that a consumer's type in period two depends on his type in period one, but also the possibility of nonrandom preferences (by taking $F_2(\theta_2 \mid \theta_1)$ to be a step function with a single step at $\theta_2 = \theta_1$) or preferences that are independent and identically distributed (iid) (by taking $F_2(\theta \mid \theta_1) = F_1(\theta)$ for all θ and θ_1). This approach does not capture the possibility that a consumer's second-period type depends on whether or not he consumed a product in period one, as might be the case if consumers grow bored or sated with a product. However, in Section 5, I provide a brief extension of the model that captures this effect.

The demand side works as follows. Taking p_1 and p_2 as given, all consumers decide in period one whether or not to buy a new unit. If they buy it, then they receive their valuations θ_1. At the start of period two, all units break with probability $1 - \alpha$ and consumers become aware of their second-period valuations. All consumers holding a used unit then decide whether to keep it or to sell it, where selling the unit yields $p_2 - \tau$, where $\tau \geq 0$ is an exogenously given transaction cost of selling on the secondary market—for simplicity, only sellers pay this fee so that a buyer of a unit in period two bears total cost p_2 regardless of whether he buys a new or used unit. Any consumer not holding a used unit decides whether to buy some unit or not, where (again) it does not matter whether a used or new unit is purchased. Finally, consumers who are holding units receive the consumption values θ_2.

The optimal decisions of consumers are as follows. At the beginning of period two, a consumer who does not hold a used unit buys some unit if $\theta_2 \geq p_2$. A consumer who is holding a used unit at the beginning of the period elects to keep it if and only if $\theta_2 \geq p_2 - \tau$.

To complete the description of the problem from the perspective of consumers, and also to derive the relationship between market prices and quantities, define the values $V^{+}(\theta_1)$ and $V^{-}(\theta_1)$

[8] Allowing for this scrap value is a great technical convenience, but is only required to handle cases where units are actually bought back by the monopolist in period two, which often will not occur. Most importantly, the primary observations of this article (that trade frictions may be preferable and that durability may be distorted to exploit changing preferences) are not driven by this assumption.

to be the expected second-period payoffs of either holding a unit at the start of period two or not, respectively, conditional on having a valuation θ_1 in period one.

$$V^+(\theta_1) = \int \max[\theta_2, p_2 - \tau]\, dF_2(\theta_2 \mid \theta_1), \quad \text{and}$$

$$V^-(\theta_1) = \int \max[\theta_2 - p_2, 0]\, dF_2(\theta_2 \mid \theta_1).$$

Let θ_1' and θ_2' denote the marginal consumers who buy units in periods one and two, respectively. Then the following must hold:

$$-p_1 + \theta_1' + \beta[\alpha V^+(\theta_1') + (1-\alpha)V^-(\theta_1')] = \beta V^-(\theta_1'),$$

so that p_1 may be expressed as

$$p_1 = \theta_1' + \beta\alpha[V^+(\theta_1') - V^-(\theta_1')]. \tag{1}$$

Note that it is only in special cases such as that with zero market frictions ($\tau = 0$) that this reduces to $p_1 = \theta_1' + \beta\alpha p_2 = \theta_1' + \beta\alpha\theta_2'$ so that the price of a unit equals simply its discounted consumption value to (marginal) consumers.[9] This fact turns out to be very important in later analysis.

Because $q_1 = 1 - F_1(\theta_1')$, equation (1) gives an expression for p_1 conditional on q_1 and p_2. To determine p_2 from q_1 and q_2 simply requires formulating the appropriate second-period market-clearance condition. To this end, let the total number of units in existence in period two be denoted by $Q = \alpha q_1 + q_2$. Recalling that $F_2(\theta_2)$ is the marginal distribution of θ_2, the following holds:

$$Q = \alpha q_1 + q_2 = 1 - F_2(p_2) + \alpha \int_{\theta_1'}^{\bar{\theta}} [F_2(p_2 \mid \theta_1) - F_2(p_2 - \tau \mid \theta_1)]\, dF_1(\theta_1). \tag{2}$$

The right-hand side of this equation simply says that anyone with a valuation θ_2 exceeding p_2 must be holding a unit in period two (either because they started the period holding a used unit and decide to keep it or because they did not start the period with a used unit but choose to buy a unit), and also that anyone with a valuation in $[p_2 - \tau, p_2]$ must be holding one if and only if they purchased a unit in period one and that unit survived to period two. Equation (2) uniquely determines p_2 given outputs q_1 and q_2, and it then follows that p_1 is uniquely determined from equation (1).

Before proceeding, I consider the special case of frictionless markets, an understanding of which is useful in later analysis. In this case, the firm solves two independent maximization problems, one associated with first-period demand and the other with second-period demand; the rental solution is obtained. To see this, note that when $\tau = 0$, profits are

$$\begin{aligned} q_1(p_1 - c(\alpha)) + \beta q_2(p_2 - c_2) &= q_1(\theta_1' + \beta\alpha p_2 - c(\alpha)) + \beta(Q - \alpha q_1)(p_2 - c_2) \\ &= q_1(\theta_1' - [c(\alpha) - \beta\alpha c_2]) + \beta Q(p_2 - c_2) \\ &= (1 - F_1(\theta_1'))(\theta_1' - [c(\alpha) - \beta\alpha c_2]) + \beta(1 - F_2(\theta_2'))(\theta_2' - c_2). \end{aligned}$$

By inspection, θ_1' and θ_2' are chosen independently to maximize two monopoly programs, one with demand $1 - F_1$ and marginal costs $c(\alpha) - \beta\alpha c_2$, and the other with demand $1 - F_2$ and marginal costs c_2.

3. Profits and trade fictions

■ As discussed in the Introduction, Swan (1980), Rust (1986), and Hendel and Lizzeri (1999) all suggest that smoothly functioning secondary markets are preferred by a monopolist. Here I

[9] For positive market frictions and changing preferences this relationship breaks down and $p_1 < \theta_1' + \beta\alpha p_2$ due to the inability to liquidate units costlessly.

show that a monopolist may, but need not, gain from market frictions. Let τ^* denote the value of market frictions that maximizes a monopolist's profits.

To assess the gains from heightened frictions, I consider both small increases in τ starting from frictionless markets and also increases in τ that are large enough to shut down secondary trade fully. Each approach leads to a slightly different intuition, and also to different results, which are united in Proposition 1 below.

To begin, suppose that markets are initially frictionless ($\tau = 0$) and that τ increases slightly, fixing the marginal consumers who buy units in each period, θ_1' and θ_2', at the levels that are optimal when $\tau = 0$ (this is equivalent to fixing q_1 and p_2). From the envelope theorem and equations (1) and (2), the effect on profits is

$$\begin{aligned}\frac{d\Pi}{d\tau} &= q_1 \frac{\partial p_1}{\partial \tau} + \beta(p_2 - c_2)\frac{\partial q_2}{\partial \tau} \\ &= -q_1 \beta\alpha F_2(p_2 \mid \theta_1') + \beta(p_2 - c_2)\alpha \int_{\theta_1'}^{\bar{\theta}} f_2(p_2 \mid \theta_1)\, dF_1(\theta_1). \end{aligned} \tag{3}$$

An increase in τ has two effects. First, it lowers the initial price of first-period units by a factor proportional to the probability that the marginal consumer in period one, θ_1', sells the good in period two (that is, has a valuation $\theta_2 \leq p_2 - \tau$, which equals p_2 when $\tau = 0$). Second, the firm sells more units in period two, where this change equals the number of consumers who bought units in period one and whose second-period valuations equal p_2 (and whose units survived to period two).

To help determine the sign of equation (3), consider optimality information regarding p_2. When markets are frictionless, $p_1 = \theta_1' + \beta\alpha p_2$ and all available units in any period are held by those with the highest current valuations, so that (as shown at the end of Section 2) the firm simply chooses p_2 to maximize profits as though it were solving a static monopoly pricing problem with a demand function determined by the marginal distribution of θ_2, given by $1 - F_2(\theta_2)$. That is, at $\tau = 0$, the optimal p_2 solves $\max_p (p - c_2)(1 - F_2(p))$, so that there is no gain to a small decrease in p_2:

$$-(1 - F_2(p_2)) + (p_2 - c_2) f_2(p_2) = 0. \tag{4}$$

Using equations (3) and (4), it is possible to identify circumstances in which the optimal market frictions are either zero or positive. I now discuss two special cases, as it is difficult to definitively sign $d\Pi/d\tau$ for arbitrary distributions.[10]

First suppose that preferences are nonrandom and distributed according to F. Also, suppose that $\theta_1' < p_2$ (for otherwise no one trades their unit in period two and an increase in τ has no effect). Considering equation (3), θ_1' trades his unit with probability one in period two, so that $F(p_2 \mid \theta_1') = 1$, and $\partial q_2/\partial\tau = f(p_2)$. Because $q_1 = 1 - F(\theta_1')$,

$$\frac{d\Pi}{d\tau} \cong -(1 - F(\theta_1')) + (p_2 - c_2) f(p_2) < -(1 - F(p_2)) + (p_2 - c_2) f(p_2) = 0.$$

This suggests that frictionless markets are preferable if consumer preferences are nonrandom; if raising τ is profitable, p_2 has not been optimally set.[11] Proposition 1 below confirms that this conclusion is correct even considering the globally optimal solution.

[10] Although it is difficult to sign $d\Pi/d\tau$ at $\tau = 0$ for an arbitrary distribution, it is straightforward to derive what the required condition is. In particular, using the basic idea behind analysis of the two special cases considered, dividing equation (3) by $\beta\alpha q_1 = \beta\alpha(1 - F_1(\theta_1'))$ and then using equation (4), it follows that $\frac{d\Pi}{d\tau} > 0$ if and only if

$$-F_2(p_2 \mid \theta_1') + (p_2 - c_2)\frac{\int_{\theta_1'}^{\bar{\theta}} f_2(p_2 \mid \theta_1)\, dF_1(\theta_1)}{1 - F_1(\theta_1')} > -(1 - F_2(p_2)) + (p_2 - c_2) f_2(p_2).$$

[11] In more detail, the intuition is as follows. Lowering p_2 raises second-period sales by $f(p_2)$, but lowers profits on the existing $(1 - F(p_2))$ units on the second-period market. This is similar to an increase in τ, which increases second-period

Now consider iid preferences: $F_2(\theta \mid \theta_1) = F_1(\theta) \equiv F(\theta)$ for all θ and θ_1. Manipulation of equation (3) reveals that an increase in τ is optimal if and only if $-F(p_2) + (p_2 - c_2)f(p_2) > 0$. Using equation (4), it can be seen that this holds if and only if

$$-F(p_2) + (p_2 - c_2)f(p_2) > -(1 - F(p_2)) + (p_2 - c_2)f(p_2) \iff 1 - F(p_2) > \frac{1}{2}.$$

Hence, $\tau^* > 0$ with iid preferences, so long as it is optimal to serve at least half the second-period market when $\tau = 0$ (which is equivalent to it being optimal to serve at least half the market in a static monopoly problem with marginal cost c_2).

The intuition follows from comparing the effect of the increase in τ with what is known about the effect of a decrease in p_2. That is, an increase in τ has the same beneficial effect on profits as a decrease in p_2 in terms of additional consumers served $f(p_2)$, but lowers profits proportional to how likely the consumer is to sell his product in period two, given by $F(p_2)$, whereas a decrease in p_2 lowers profits based on how many consumers actually hold units in period two, given by $1 - F(p_2)$. Hence, when $F(p_2) < 1 - F(p_2)$, an increase in τ from zero is more rewarding than a small decrease in p_2, which itself has a zero effect on profits because p_2 is presumed optimal; this means an increase in τ is profitable.

An additional result can be obtained in the iid case by considering a very large increase in τ as opposed to a very small one. Suppose that markets are originally frictionless but then become fully closed, fixing the marginal consumers θ_1' and θ_2'. This leads to three effects. First, some consumers who otherwise would not have held units in the second period now do. Second, because the original price p_2 continues to prevail, no fewer consumers buy a unit in period two. Third, the firm bears additional costs from expanding second-period production. The overall effect is

$$\begin{aligned} &q_1 \Delta p_1 + \beta(p_2 - c_2)\Delta q_2 \\ &= q_1 \beta\alpha \int_0^{p_2} (\theta - p_2)\, dF(\theta) + \beta(p_2 - c_2)\alpha q_1 F(p_2) \\ &= \beta\alpha q_1 \int_0^{p_2} (\theta - c_2)\, dF(\theta). \end{aligned} \tag{5}$$

It can be shown that this expression is positive whenever c_2 is small, ensuring that positive frictions are optimal in such cases.

The analysis above is summarized in the following proposition, the proof of which handles any technical details neglected above (proofs of all propositions are in the Appendix).

Proposition 1. The following statements are true:

(i) if preferences are nonrandom, then frictionless markets are optimal: $\tau^* = 0$;
(ii) if preferences are iid, and either
 (a) c_2 is sufficiently small, or
 (b) $1 - F(p^*) > \frac{1}{2}$, where $p^* = \arg\max_p (p - c_2)(1 - F(p))$,
 then positive market frictions are strictly optimal: $\tau^* > 0$.

Proposition 1 indicates that positive frictions may, but need not, raise monopoly profits. A broad intuition for why market frictions may be optimal is that they allow a type of price discrimination that is not possible in their absence. In particular, they allow the monopolist to keep additional units in the hands of individuals who have lower second-period valuations, so long as such consumers had first-period valuations that were sufficiently high for them to purchase units.

One might wonder whether allowing durability to be endogenous overturns the conclusion that market frictions may be preferable. It does not, as is easiest to see in the case where production

sales by the same amount but which lowers the price on all first-period units. Because there are more first-period units than second-period units (for otherwise frictions do not matter with nonrandom preferences), an increase in τ is strictly worse than a decrease in p_2.

costs are literally zero and preferences are iid. Because the proof of the relevant part of Proposition 1 works for any given $\alpha > 0$, the only way in which the proposition might fail is if the optimal durability were $\alpha = 0$. But with zero costs, $\alpha = 0$ cannot be the only optimal durability under frictionless markets, and so there is some $\alpha > 0$ that is also optimal. But then the logic of the proof of Proposition 1 applies.

Because it will be useful in later analysis, I end this section by providing a bit more detail on the forces at work with arbitrary preferences by once again considering a potentially large change in τ. To that end, consider the comparative static on profits of moving to frictionless markets from a starting place with positive frictions, while fixing the marginal buyers θ_1' and θ_2'. Denote the change in profits from removing these frictions as $\Delta\Pi$:

$$\Delta\Pi = q_1 \Delta p_1 + \beta(p_2 - c_2)\Delta q_2.$$

Note that

$$\Delta p_1 = \beta\alpha\tau F_2(p_2 - \tau \mid \theta_1') + \beta\alpha \int_{p_2-\tau}^{p_2} (p_2 - \theta) dF_2(\theta \mid \theta_1').$$

The reason is that eliminating transaction costs causes the marginal consumer to avoid those he otherwise would have borne, and also causes him to sell his unit rather than keep it whenever his second-period valuation lies in $[p_2 - \tau, p_2]$.

Also note that

$$\Delta q_2 = -\alpha \int_{\theta_1'}^{\bar{\theta}} \left[\int_{p_2-\tau}^{p_2} dF_2(\theta \mid \theta_1) \right] dF_1(\theta_1),$$

because the monopolist must reduce output to compensate for those units that become traded consequent to the elimination of frictions.

Combining these elements yields

$$\begin{aligned} \Delta\Pi = {} & q_1\beta\alpha\tau F_2(p_2 - \tau \mid \theta_1') - q_1\beta\alpha \int_{p_2-\tau}^{p_2} \theta dF_2(\theta \mid \theta_1') - \beta c_2 \Delta q_2 \\ & + \beta\alpha p_2 \left\{ q_1 \int_{p_2-\tau}^{p_2} dF_2(\theta \mid \theta_1') - \int_{\theta_1'}^{\bar{\theta}} \left[\int_{p_2-\tau}^{p_2} dF_2(\theta \mid \theta_1) \right] dF_1(\theta_1) \right\}. \end{aligned} \tag{6}$$

$\Delta\Pi$ shows the four effects on profits from a lowering of τ to zero. First, transaction costs τ are avoided, raising the price that the marginal consumer θ_1' will pay commensurate to the expected level of costs. Second, the marginal consumer expects to no longer hold units in period two when his valuation lies in the range $[p_2 - \tau, p_2]$; the price discrimination effect disappears, pushing toward lower profits. Third, fewer units need to be produced and hence costs are saved.

The fourth effect—that in curly brackets above—is that the "effective number" of units sold by the firm at price p_2 changes. By "effective number" I mean the number sold including both actual second-period sales and also the portion of the first-period price that incorporates p_2. Precisely, removing frictions means the firm can charge all first-period buyers a premium to account for the fact that they will be able to sell their units in the second period when their valuation lies in the range $[p_2 - \tau, p_2]$; the exact level of this premium depends on the likelihood the marginal consumer θ_1' will be in this region. But on the other hand, the firm loses second-period sales, where these losses depend on the total number of inframarginal consumers (who bought in period one) whose valuations lie in $[p_2 - \tau, p_2]$ in period two.

4. Endogenous durability

■ In this section, I endogenize durability and ask whether a monopolist wishes to manipulate it to interfere with the secondary market. At the start of period one, the monopolist chooses $\alpha \in [0, 1]$ in addition to output levels.

The literature has suggested several different views on whether there are gains from manipulating durability. The one most directly relevant to my own work is that articulated by Swan (1970, 1971, 1972) and Sieper and Swan (1973), who argue forcefully that if a monopolist has commitment power and durability is a measure of how long a unit will provide utility to consumers, then durability is chosen strictly to minimize costs. A looser view of Swan's result is that if costs are zero then durability has no impact on the maximum achievable profits.[12] In this sense, durability does not matter.

In contrast to that assessment, I show that durability does matter: it influences the maximum attainable profits even with zero costs, and for any cost structure, incentives exist to distort it except in the special case of completely frictionless markets.

I begin by considering durability manipulation with frictionless markets and then take up the case of market frictions. After that, I consider how a monopolist's durability choice differs from that of a social planner.

□ **Durability choice with no trade frictions.** Consider the total costs that a monopolist bears given that the total number of units Q in period two is fixed:

$$q_1 c(\alpha) + \beta q_2 c_2 = q_1 c(\alpha) + \beta(Q - \alpha q_1)c_2.$$

Define the durability that minimizes these costs as $\alpha_{\min}$:

$$\alpha_{\min} = \arg\min_{\alpha}[c(\alpha) - \beta\alpha c_2]. \tag{7}$$

Proposition 2. Suppose that there are no secondary-market frictions ($\tau = 0$), and fix the marginal buyers in periods one and two (that is, fix θ_1' and θ_2'). Then the following hold.

(i) Revenue $q_1 p_1 + \beta q_2 p_2$ is invariant to α.
(ii) The profit-maximizing durability level minimizes production costs: $\alpha^* = \alpha_{\min}$.

Proposition 2 confirms that Swan's intuition holds even with random preferences; durability manipulation is not a useful tool for influencing revenues when secondary trade is frictionless. Instead, a monopolist exerts its market power by limiting which consumers hold units in each period, and separately chooses durability to minimize costs.

When there are no secondary-market frictions, the price of a new unit in period one perfectly reflects the fact that this unit will be worth p_2 to the holder in period two. Consequently, for example, although reducing durability may raise the number of second-period sales at price p_2, the price paid for units in period one falls to offset perfectly the period two gain.

To see this, note from equation (1) that $p_1 = \theta_1' + \beta\alpha p_2$, meaning that revenue is

$$\begin{aligned} q_1 p_1 + \beta q_2 p_2 &= q_1(\theta_1' + \beta\alpha p_2) + \beta(Q - \alpha q_1)p_2 \\ &= q_1\theta_1' + \beta Q p_2 = q_1\theta_1' + \beta Q \theta_2' = (1 - F_1(\theta_1'))\theta_1' + \beta(1 - F_2(\theta_2'))\theta_2', \end{aligned}$$

where the final equality follows from equation (2). Because this is independent of α, durability as such plays no role in the ability of the firm to exert its market power—only the identities of the marginal consumers matter, and durability is chosen to minimize costs.

□ **Durability choice with trade frictions.** I now show that secondary-market frictions have a major qualitative effect on durability choice. Instead of influencing only costs, durability influences revenue and indeed the maximum obtainable profit of the firm. I also show that whether a firm prefers high or low durability depends closely on its preferences for market frictions.

[12] Precisely, given a change in durability, a monopolist can simply adjust future production so as to keep the total number of units on the market fixed in all periods and still achieve the same profits as before.

Conceptually, the reason that durability must influence revenues in the presence of market frictions is that durability influences which consumers actually hold units in period two. That is, fixing θ_1' and θ_2', an increase in durability leads to more consumers with second-period valuations in the range $[p_2 - \tau, p_2]$ holding units, whereas with frictionless markets this range is zero and hence there is no change in which consumers hold units.

More technically, consider fixing θ_1' and θ_2' and ignoring changes in costs. Then,

$$\frac{\partial \Pi}{\partial \alpha} = -q_1 \beta \tau F_2(p_2 - \tau \mid \theta_1') + q_1 \beta \int_{p_2-\tau}^{p_2} \theta dF_2(\theta \mid \theta_1')$$
$$+ \beta p_2 \left\{ q_1 \left[1 - \int_{p_2-\tau}^{p_2} dF_2(\theta \mid \theta_1') \right] - \int_{\theta_1'}^{\bar{\theta}} \left[1 - \int_{p_2-\tau}^{p_2} dF_2(\theta \mid \theta_1) \right] dF_1(\theta_1) \right\}. \quad (8)$$

This expression, which is typically nonzero for $\tau > 0$, is composed of three main terms that are reminiscent of those describing how profits are influenced by eliminating market frictions as presented in equation (6).[13] The first term indicates that the marginal consumer from period one tends to bear more future transaction costs when units last longer, and this pushes toward a lower p_1. The second term indicates that an increase in durability increases the number of consumers who hold a unit in period two despite their valuation being lower than the market price, and this effect pushes toward higher profits through the effect on p_1—the price-discrimination effect of market frictions identified in Section 3 is strengthened when units last longer.

The intuition behind the third, bracketed, term is more subtle, as was the fourth term in equation (6). The first component of it derives from the fact that the firm is able to charge a fraction of p_2 to all q_1 initial customers, where this fraction is determined by the preferences of the marginal first-period buyer θ_1'. In particular, the fraction is the probability that the marginal consumer θ_1' will gain p_2 in period two, either by reselling the good or by being spared the cost of buying a new unit, and hence this increases with α. The second component measures the growth in the number of units that actually compete against the firm in period two, which is determined by the average probability that an inframarginal buyer from period one has a second-period valuation outside of $[p_2 - \tau, p_2]$, not just the probability that the marginal buyer has such a valuation.

Despite the complexity of durability's impact on profits, there are strong qualitative results regarding the relationship between optimal durability and a monopolist's preferences for market frictions. The crucial intuition flows from the tight relationship between how profits are influenced by a change in durability and how they are influenced by the elimination of trade frictions, fixing the marginal consumers θ_1' and θ_2'. In particular, inspection of equations (6) and (8) reveals that, ignoring costs,

$$\Delta \Pi = -\alpha \frac{\partial \Pi}{\partial \alpha}. \quad (9)$$

In words, lowering τ to zero while fixing the values θ_1', θ_2', and α has an effect on profits that is proportional to marginally reducing durability.

Recall that $\alpha_{\min}$, given in equation (7), is the durability level chosen when second-hand trade is frictionless. Let $\Pi^*(\tau)$ denote maximized profits given τ, and let $\alpha^*(\tau)$ denote optimal durability given τ.

Proposition 3. Let trade frictions be positive ($\tau > 0$), $\alpha_{\min} \in (0, 1)$, and $c''(\alpha) > 0$. Then the following statements are true.

(i) Suppose that the monopolist prefers the existing level of trade frictions $\tau > 0$ to the case of frictionless markets, so that $\Pi^*(\tau) > \Pi^*(0)$. Then planned durability is strictly optimal: the unique profit-maximizing level of durability is $\alpha^*(\tau) > \alpha_{\min}$.

(ii) Suppose that the monopolist prefers frictionless markets to the actual market frictions τ, even fixing the marginal consumers and durability that are optimal at τ; that is, suppose that

[13] If costs were included, then there would be a fourth term here as there is in equation (6).

$\Delta\Pi > 0$. Then planned obsolescence is strictly optimal: the unique profit-maximizing level of durability is $\alpha^*(\tau) < \alpha_{\min}$.

Proposition 3 says that whether a monopolist underinvests or instead overinvests in durability relative to $\alpha_{\min}$ is determined by its preferences for market frictions. More precisely, the first part of Proposition 3 says that when a monopolist prefers secondary-market frictions it also prefers planned durability rather than planned obsolescence. The intuition follows from that for why secondary-market frictions can be optimal in the first place, as discussed in Section 3; because such frictions allow the monopolist to exploit the randomness of consumer preferences to segment better the second-period market, and because this price discrimination is predicated on having units in fact survive to later periods, the incentives for durability are increased whenever such price discrimination is desirable. In other words, durability complements market frictions whenever market frictions are preferred.

In contrast, the second part of Proposition 3 indicates that planned obsolescence may arise when the firm prefers frictionless markets but actually faces positive frictions. The intuition is as follows. When the firm does not wish to engage in price discrimination enabled by market frictions, it can partially avoid it by setting durability to lower levels, because this reduces the number of lower-valuation individuals holding units in the second period. Thus, planned obsolescence is a substitute for frictionless secondary markets.[14]

In the special case in which costs are zero ($c(\alpha) = c_2 = 0$), starker results exist; it can be shown that either perfectly durable ($\alpha = 1$) or perfectly nondurable ($\alpha = 0$) goods are optimal.[15] Also, the second part of Proposition 3 can be strengthened so that $\Pi^*(0) - \Pi^*(\tau) \geq 0$ implies $\alpha^* = 0$, as opposed to requiring that the firm prefers to remove market frictions even if it is unable to optimize other variables in response.[16]

The case of zero costs is also of interest because it demonstrates that durability can influence the maximum obtainable profits for reasons unrelated to costs. In particular, this follows from the fact that the firm has a strict preference for $\alpha = 1$ whenever it prefers the existing (positive) transaction costs.

Most broadly, Proposition 3 shows that Swan's famous Independence Result and related intuitions readily fail to hold when there are market frictions and consumer preferences change over time. Revenue and indeed maximum revenue are influenced by durability, and the cost-minimizing level that would emerge under frictionless markets is not optimal in the presence of frictions.

The reason Swan's result does not hold here is that the substitutability between old and new units breaks down in the presence of transaction costs (Swan only considers frictionless markets). That is, durability influences which consumers hold units in period two when there are market frictions, fixing the marginal buyers, and this causes revenue to be influenced by durability as opposed to only costs.

Although Proposition 3 takes τ as exogenous, there are some circumstances in which firms can influence the ease with which people exchange used goods. For example, digital rights management software allows sellers of digital content to limit how such content is used. Consider

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[14] Note that leasing serves a role similar to setting low durability levels, at least if so doing avoids the transaction costs τ. The reason is that leasing ensures that only the highest-valuation individuals hold units in period two, which is what setting a very low durability accomplishes.

[15] To see the claim regarding $\alpha^* = 1$, consider the following. If costs are zero, then, using equation (9),

$$\frac{\partial \Pi}{\partial \alpha} = -\alpha^{-1}\Delta\Pi \geq \alpha^{-1}[\Pi^*(\tau) - \Pi^*(0)] > 0,$$

where the first inequality follows from the fact that $-\Delta\Pi$ is the difference in profits that occurs when frictions are eliminated but the firm is not allowed to optimize θ_1' and θ_2', whereas $\Pi^*(0) - \Pi^*(\tau)$ is the difference when the firm optimizes, and the second inequality follows by hypothesis. The claim regarding $\alpha = 0$ follows.

[16] Actually, with zero costs it can never be that $\Pi^*(0) - \Pi^*(\tau) > 0$, because if $\tau > 0$, then setting $\alpha = 0$ and choosing q_1 and Q as would be optimal when $\tau = 0$ allows the firm to achieve the same profits as in that case. If, however, $\Pi^*(0) - \Pi^*(\tau) = 0$, then $\alpha = 0$ is optimal even if $\tau > 0$.

that the electronic-book readers of both Amazon and Barnes & Noble prevent users from selling used books to other consumers.[17] Similarly, Universal Studios litigated against Redbox, seeking among other provisions to establish a minimum rental rate for DVDs and to enforce the destruction rather than resale of used DVDs. In contrast, many new car dealers facilitate trade in used cars, often with the blessing of manufacturers who in some cases provide certification programs to guarantee the quality of used units.

In cases where firms can indeed (costlessly) control market frictions, Propositions 2 and 3 together indicate that there is no role for planned obsolescence. Instead, the firm would either choose frictionless markets and (by Proposition 2) care about durability only as a tool to lower costs (or, if costs are zero, be completely unconcerned with durability) or choose positive market frictions and (by Proposition 3 and revealed preference) overinvest in durability (or, if costs are zero, set $\alpha = 1$).

□ **The second best.** I close this section with a brief discussion of the second best in the presence of market frictions. I define the second-best solution of the social planner to be that which maximizes total surplus, fixing the number of physical units on the market in each period. Thus, the question is whether a planner would prefer lower or higher durability than a monopolist, given q_1 and Q. The reason for fixing the number of units on the market is that any welfare comparison that does not do so suffers from the fact that a social planner will naturally wish to increase durability so as to raise the number of units being held because this ameliorates the underconsumption inefficiency brought about by monopoly power.

As mentioned earlier, when the number of units on the market is fixed and there are market frictions, durability choice influences who holds the units. For example, if durability is zero, then in the second period all units in existence are purchased as new and held by the highest-valuation consumers that period. On the other hand, when durability is high, many more units will be held by lower-valuation consumers in the second period. Thus, the question here is whether a social planner prefers a different distribution across consumers of available units than a monopolist does. With iid preferences, the answer is clear.

Proposition 4. Let consumer valuations be iid. In the second best in which q_1 and Q are fixed, with $Q \geq q_1$, the following statements are true.

(i) If secondary markets are frictionless, then a social planner chooses the same durability that a monopolist does, and that value is α_{min}.
(ii) If there are positive secondary-market frictions, then a social planner chooses a lower durability than a monopolist does.

The intuition behind Proposition 4 is as follows. When total market quantities q_1 and Q are fixed, an increase in durability has three effects on monopoly profits. First, if transaction costs are positive, the number of units held by their original owners increases, which means the static inefficiency associated with misallocation of units also increases. This effect lowers profits. Second, the overall costs change. Third, because fewer units flow to new buyers in period two, p_2 increases and this raises profits, so long as $q_2 \geq 0$ (which is guaranteed by the assumption that $Q \geq q_1$).

A social planner, however, sees only the first two of these three effects. That is, the planner cares about the worsened allocation of units brought about by heightened durability and also about changes in overall costs borne, but discounts the fact that the firm enjoys higher revenues from an increased p_2. Consequently, a planner prefers a lower level of durability than a monopolist.

When secondary-market frictions vanish, however, the second-period price is independent of α and instead is completely determined by the number of units in existence in the second

[17] Electronic books purchased for Amazon's Kindle cannot be shared or resold at all. Barnes & Noble's Nook reader allows electronic books to be shared for up to 14 days.

period, because these units are always held by the highest-valuation consumers. Hence, both the first and the third effect disappear and both a social planner and a monopolist choose the same durability, which is the one that minimizes costs. Thus, Proposition 4 directly confirms (the social welfare aspect of) Swan's Independence Result in the absence of market frictions.

5. Extension: declining value of consumption

■ There are many goods for which it is reasonable to assume that a consumer's per-period valuation declines with repeat consumption. For instance, the enjoyment from books or music may be highest when they have been experienced only a small number of times.[18]

Here I extend the model to allow for such preferences. I show that the intuition from earlier analysis concerning the role of secondary-market frictions continues to hold: it may be optimal for a monopolist to shut down secondary trade. In addition, I highlight recent evidence from the book market that is consistent with this result. Finally, I argue that this analysis provides a new perspective on the famous observation that textbook manufacturers seek to "close the market" for used textbooks.

□ **The model.** All elements of the model are as described in Section 2 except as follows. There are two cohorts of consumers, each of mass one, with one cohort arriving in each period. Consumers from the first cohort are active for two periods, whereas those from the second are active for but a single period. Consumers are homogeneous within a cohort, and any consumer gains a utility flow of θ the first time she consumes the product, but gains only $\rho\theta$ the second time, where $\rho \in (0, 1)$. Thus, for example, a consumer who holds a unit in both periods receives gross utility of $(1 + \beta\rho)\theta$. For simplicity, I fix $\alpha = 1$ and define $c \leq (1 + \beta\rho)\theta$ to be the marginal production cost in either period.

Proposition 5. Consider the two-cohort model in which consumer valuations decline based on whether or not they have previously consumed the product. Then the profit-maximizing level of market frictions is such that either markets are frictionless or fully closed: $\tau^* \in \{0, \infty\}$. Furthermore, profits are higher under closed secondary markets ($\tau = \infty$) than frictionless secondary markets ($\tau = 0$) if and only if $\rho\theta > c$.

As in Proposition 1, closing secondary markets is optimal when the marginal cost of production is small relative to the utility gained from ensuring that more consumers hold units in later periods, where this gain is indexed by ρ. Closing markets leads to the first cohort keeping their units in the second period but also causes the firm to bear more costs, as it raises second-period production to serve the later cohort.

Closing markets therefore allows the entire market to be served in both periods. Moreover, this is done while still setting $p_2 = \theta$, the reservation value of the second cohort, whereas serving all consumers with open markets would require setting $p_2 = \rho\theta$. Hence, as in earlier analysis, secondary-market frictions may help the firm better segment the market.

Implicit in Proposition 5 is the fact that social welfare improves when secondary markets are shut down and the marginal cost of production is small. The reasoning is straightforward: under such parameterizations, closing secondary markets leads to an expansion in the supply of new units in later periods so that the overall number of individuals holding units increases, and moreover all consumers value the units above marginal cost.

□ **Evidence from the book market.** In 2002, the Authors Guild and the Association of American Publishers criticized Amazon's newly implemented market for used books, arguing

[18] This is not to say that the value may not remain positive, or that certain select favorites will not always be treasured, but merely that most individuals seek out new books and music over time rather than constantly reexperiencing the ones they already possess.

that it would restrict new book sales. Although their concern is at odds with the assertions of Swan (1980), Rust (1986), and Hendel and Lizzeri (1999), Proposition 5 provides a theoretical explanation. Namely, because the repeat consumption value of books may be lower than the initial consumption value, closing secondary markets may enable profitable price discrimination by both keeping the price for new books high yet inducing consumers to hold onto their used books, upon which they still place positive (if lowered) consumption value.

As a second application, note that Proposition 5 is also consistent with the actions of Amazon and Barnes & Noble involving their recently introduced electronic-book readers, called the Kindle and Nook, respectively. The Kindle and Nook allow consumers to purchase and download books and then read them. However, through the use of digital rights management software, resale or trade of the books is prohibited between consumers. Indeed, because the marginal cost of production is extremely low for electronic books, the gains from the type of price discrimination discussed above would seemingly be large.

As a third application of Proposition 5, consider the market specifically for textbooks.[19] Publishers have often been accused of introducing new versions of textbooks solely to kill off the secondary market. To connect this to the current model, suppose that students who take a class initially have a high valuation for the book but that it falls once they are finished with the class. Nonetheless, this residual valuation is still positive, as might be the case if former students use the book as an occasional reference or simply enjoy displaying it or holding it for nostalgic value. Also, interpret τ not as the cost of trade as such but instead as the cost to a student currently taking the class using an older textbook.[20] Thus, τ measures disutility from using a version of the textbook that may have different examples or exercises or be laid out differently from the version used by the course instructor. Proposition 5 then indicates that a publisher may prefer to introduce new versions of textbooks that are incompatible with ones available on the used market.

Two features that distinguish this view of the textbook market are as follows. First, there need be no "meaningful" changes to the actual content of new editions. Rather, it is enough that they are laid out in a different manner as far as chapters or pages go, or have different exercises or examples, for instance. Thus, no significant investment is required by firms besides convincing professors to assign the most recent edition. This is in contrast to explanations for this phenomenon such as that in Waldman (1996b) in which a monopolist might make old textbooks obsolete by investing in higher-quality versions.[21] Indeed, in Waldman's model there is too much investment in quality from the firm's standpoint, whereas in my analysis quality does not change at all.

Second, but closely related, in the view put forth here, students who previously took a course would have no need to upgrade to newer editions; after all, the different editions may not differ as far as content. Indeed, it seems likely that most former students do not upgrade to newer versions over time, whereas in Waldman (1993, 1996b), consumers who purchase in early periods upgrade to higher-quality versions in later periods; similar upgrading is important in the analysis of Fudenberg and Tirole (1998).

6. Extension: entry of new consumers

■ I showed in Section 3 that secondary-market frictions can be profitable when valuations change over time. I also showed that, when preferences were nonrandom, frictionless markets were preferred. In this section, I explore the robustness of this second conclusion by allowing for the entry of additional consumers in period two.

Intuitively, even when preferences do not change over time, entry of additional consumers changes the overall distribution of valuations, and this means that the valuations of first-period

[19] See Chevalier and Goolsbee (2009) for a recent empirical contribution suggesting that students are indeed forward-looking when they purchase their textbooks.

[20] This is a slight additional modification of the model presented earlier, because τ was assumed to be a cost borne by the seller rather than the purchaser.

[21] Waldman (1993) also considers planned obsolescence in a setting with network effects.

consumers shift within the overall distribution over time. This is very similar to what happens in the basic model of changing consumer preferences, raising the question of whether such entry might lead to the optimality of trade frictions. It turns out that the answer is yes.

To identify when entry of new consumers leads the monopolist to prefer positive trade frictions, consider the following extension of the model of Section 2. All elements of the model are the same as before, except for the following changes. In period two, a new cohort of consumers appears (for only that period, because there are still only two periods). This cohort has a mass of one, and is distributed on $[0, \bar{\theta}]$ according to G, where both $\theta(1 - G(\theta))$ and $\theta(1 - F(\theta))$ are quasiconcave. Finally, costs are zero ($c(\alpha) = c_2 = 0$ for all α).

Suppose that

$$\arg\max_p p(1 - F(p)) < \arg\max_p p(1 - G(p)).$$

As discussed earlier, when $\tau = 0$, the actual problem the firm faces is equivalent to maximizing separately the profits in each period as though it faced two static maximization programs, in this case one with demand given by $1 - F(p)$ and the other with demand given by $1 - F(p) + 1 - G(p)$; this yields an outcome equivalent to the rental solution. Hence, optimally $\theta_1' = \arg\max_p p(1 - F(p))$. Additionally, due to the assumed quasiconcavity, the condition above implies that $p_2 > \theta_1'$, so that some consumers sell their units in period two.[22]

With this in mind, suppose that markets are frictionless and the firm has optimized, and consider the effect of fully shutting down secondary markets, fixing θ_1' and $\theta_2' = p_2$. There is a decrease in p_1 of $\beta\alpha(p_2 - \theta_1')$ because the marginal first-period consumer becomes unable to sell a surviving unit but instead consumes it in period two. Also, the firm sells $\alpha(F(p_2) - F(\theta_1'))$ more units in period two, so that the overall profit effect is

$$\begin{aligned} & q_1\Delta p_1 + \beta p_2 \Delta q_2 \\ & = -q_1\beta\alpha(p_2 - \theta_1') + \beta p_2\alpha(F(p_2) - F(\theta_1')) \\ & \cong -(1 - F(\theta_1'))(p_2 - \theta_1') - p_2[(1 - F(p_2)) - (1 - F(\theta_1'))] \\ & = \theta_1'(1 - F(\theta_1')) - p_2(1 - F(p_2)) > 0, \end{aligned}$$

where the inequality follows from the fact that θ_1' is chosen to maximize $\theta_1'(1 - F(\theta_1'))$, whereas p_2 is not chosen to maximize $p_2(1 - F(p_2))$.[23]

It follows that $\tau^* > 0$ whenever $\arg\max_p p(1 - F(p)) < \arg\max_p p(1 - G(p))$. This condition is also necessary for the optimality of trade frictions.

Proposition 6. Consider the model of new consumer entry and nonrandom preferences. If $\arg\max_p p(1 - F(p)) < \arg\max_p p(1 - G(p))$, then secondary-market frictions are strictly optimal. Otherwise, frictionless markets are optimal.

Proposition 6 supports the overall finding of Section 3 that market frictions can enable profitable price discrimination when the location of consumers within the overall distribution of valuations changes over time. In empirical applications, it is possible that the characteristics of new cohorts are random, so that sometimes the requirement of the proposition is satisfied even though other times it is not. Because frictions do not influence profits at all when this requirement is not met (because no units are traded in that case), this suggests that frictions are optimal in a broad class of situations involving new consumer entry.

[22] Because the firm chooses p_2 to maximize $p_2(1 - F(p_2)) + p_2(1 - G(p_2))$, which is the sum of two quasiconcave functions, the optimal p_2 lies between $\arg\max_p p(1 - F(p))$ and $\arg\max_p p(1 - G(p))$.

[23] An intuitive way of seeing why the final expression must capture the effect on profits (up to the proportionality constant $\beta\alpha$) of closing secondary markets is by recalling that the frictionless solution is equivalent to the rental solution, and that starting from that point, imposing frictions means that the firm charges an additional $\beta\alpha\theta_1'$ on all $1 - F(\theta_1')$ first-period units but loses the opportunity to sell $\alpha(1 - F(p_2))$ units at discounted price βp_2 (because this many consumers will now already be holding a unit).

7. Conclusion

■ The existing literature on durable goods has emphasized that secondary-market frictions impose no profitability constraint on a monopolist, so that frictionless secondary markets are always preferred. I have shown that allowing for consumer preferences that change over time readily overturns this prediction.

Additionally, I have shown that if market frictions are positive, then durability plays an important role in profit maximization beyond that of cost minimization, so that Swan's Independence Result is overturned. Finally, I identified a strong equilibrium relationship between a firm's preferences for durability and market frictions.

Appendix

This Appendix contains proofs of propositions that were omitted from the main body of the text.

Proof of Proposition 1. Consider first the claim regarding nonrandom preferences. Using an approach somewhat different from in the text, I will show that if the firm can costlessly choose τ then it selects $\tau = 0$, which implies the result. To this end, take θ_1', θ_2', and τ where, without loss of generality, $\theta_2' - \tau \geq \theta_1'$. Note that $p_2 = \theta_2'$, $p_1 = \theta_1' + \beta\alpha(\theta_2' - \tau)$, and $q_2 = (1-\alpha)(1-F(p_2)) - \alpha[F(p_2-\tau) - F(\theta_1')]$, because the firm sells new units in period two exactly to those $(1-\alpha)(1-F(p_2))$ consumers whose valuations are sufficiently high but whose units broke, minus the $\alpha[F(p_2-\tau) - F(\theta_1')]$ units that lower-valuation consumers sell. Thus, profits $q_1(p_1 - c(\alpha)) + \beta q_2(p_2 - c_2)$ are

$$
\begin{aligned}
&(p_1 - c(\alpha))(1 - F(\theta_1')) + \beta(p_2 - c_2)[(1-\alpha)(1-F(p_2)) - \alpha(F(p_2-\tau) - F(\theta_1'))] \\
&= -\beta\alpha\tau(F(\theta_2' - \tau) - F(\theta_1')) + (\theta_1' - (c(\alpha) - \beta\alpha c_2))(1 - F(\theta_1')) \\
&\quad + \beta\alpha(\theta_2' - \tau - c_2)(1 - F(\theta_2' - \tau)) + \beta(1-\alpha)(\theta_2' - c_2)(1 - F(\theta_2')),
\end{aligned}
$$

where I have omitted extensive algebra from this derivation.

Now consider the transformations $\tilde{\theta}_1 = \theta_1'$, $\tilde{\theta}_2 = \theta_2' - \tau$, and $\tilde{\theta}_3 = \theta_2'$. Ignoring the term $-\beta\alpha\tau(F(\theta_2' - \tau) - F(\theta_1')) = -\beta\alpha\tau(F(\tilde{\theta}_2) - F(\tilde{\theta}_1))$ for the moment, consider maximizing the remaining profit terms

$$
(\tilde{\theta}_1 - (c(\alpha) - \beta\alpha c_2))(1 - F(\tilde{\theta}_1)) + \beta\alpha(\tilde{\theta}_2 - c_2)(1 - F(\tilde{\theta}_2)) + \beta(1-\alpha)(\tilde{\theta}_3 - c_2)(1 - F(\tilde{\theta}_3)),
$$

subject, of course, to the constraints $\tilde{\theta}_1 \leq \tilde{\theta}_2 \leq \tilde{\theta}_3$. Clearly, the solution exhibits $\tilde{\theta}_2 = \tilde{\theta}_3$. In terms of the untransformed problem, this means that $\tau = 0$, which also happens to maximize the neglected term $-\beta\alpha\tau(F(\tilde{\theta}_2) - F(\tilde{\theta}_1))$. Hence, the solution to the modified problem solves the original problem, which means that $\tau^* = 0$.

Now consider part (ii) of the proposition. The second claim is proven in the text, and so consider the first. In the text I claimed that closing markets leads to the change in profits

$$
\begin{aligned}
&q_1\Delta p_1 + \beta(p_2 - c_2)\Delta q_2 \\
&= q_1\beta\alpha\int_0^{p_2}(\theta - p_2)\,dF(\theta) + \beta(p_2 - c_2)\alpha q_1 F(p_2) \\
&= q_1\beta\alpha\int_0^{p_2}(\theta - c_2)\,dF(\theta).
\end{aligned}
\tag{A1}
$$

The first equality follows from equations (1) and (2). In particular, the change in p_1 reflects the fact that consumers whose second-period valuations are less than p_2 now keep units instead of selling them so long as the units they purchased in period one survive, and the change in q_2 reflects the fact that the firm must now produce a corresponding number of units in period two to satisfy demand at p_2.

Because $\alpha \in (0, 1)$ and p_2 is bounded away from zero as c_2 becomes small under open markets, this is positive and the result follows. The reason that p_2 cannot approach zero is that in such a case the firm would not be receiving any profits associated with second-period consumption, and it could do better by reducing the number of units available in the second period in order to raise p_2 and overall profits.

Proof of Proposition 2. The proof is straightforward and given in the body of the text.

Proof of Proposition 3. To prove this result, I extend equation (9) to the case of positive costs. Incorporating costs means that profits are

$$
\Pi = q_1(p_1 - c(\alpha)) + \beta q_2 p_2 - \beta c_2 q_2.
$$

Using equation (6),

$$\Delta\Pi = q_1\beta\alpha\tau F_2(p_2-\tau \mid \theta_1') - q_1\beta\alpha\int_{p_2-\tau}^{p_2}\theta dF_2(\theta \mid \theta_1')$$
$$+\beta\alpha p_2\left\{q_1\int_{p_2-\tau}^{p_2}dF_2(\theta \mid \theta_1') - \int_{\theta_1'}^{\bar{\theta}}\left[\int_{p_2-\tau}^{p_2}dF_2(\theta \mid \theta_1)\right]dF_1(\theta_1)\right\} - \beta c_2\Delta q_2. \tag{A2}$$

Now consider the profit effect of a small increase in α from the actual level of τ.

$$\frac{\partial\Pi}{\partial\alpha} = -q_1\beta\tau F_2(p_2-\tau \mid \theta_1') + q_1\beta\int_{p_2-\tau}^{p_2}\theta dF_2(\theta \mid \theta_1')$$
$$+\beta p_2\left\{q_1\left[1-\int_{p_2-\tau}^{p_2}dF_2(\theta \mid \theta_1')\right] - \int_{\theta_1'}^{\bar{\theta}}\left[1-\int_{p_2-\tau}^{p_2}dF_2(\theta \mid \theta_1)\right]dF_1(\theta_1)\right\}$$
$$-\beta c_2\frac{\partial}{\partial\alpha}q_2 - q_1c'(\alpha)$$
$$= -q_1\beta\tau F_2(p_2-\tau \mid \theta_1') + q_1\beta\int_{p_2-\tau}^{p_2}\theta dF_2(\theta \mid \theta_1')$$
$$+\beta p_2\left\{-q_1\int_{p_2-\tau}^{p_2}dF_2(\theta \mid \theta_1') + \int_{\theta_1'}^{\bar{\theta}}\int_{p_2-\tau}^{p_2}dF_2(\theta \mid \theta_1)dF_1(\theta_1)\right\} - \beta c_2\frac{\partial}{\partial\alpha}q_2 - q_1c'(\alpha). \tag{A3}$$

Now, because the marginal buyers are fixed, equation (2) gives

$$\frac{\partial}{\partial\alpha}q_2 = -q_1 + \int_{\theta_1'}^{\bar{\theta}}\left[F_2(p_2 \mid \theta_1) - F_2(p_2-\tau \mid \theta_1)\right]dF_1(\theta_1). \tag{A4}$$

Note that from this it follows that

$$\frac{\partial^2\Pi}{\partial\alpha\partial\alpha} = -q_1c''(\alpha) < 0.$$

From equations (A2) and (A3), it can be seen that

$$\frac{\partial\Pi}{\partial\alpha} = -\frac{1}{\alpha}(\Delta\Pi + \beta c_2\Delta q_2) - \beta c_2\frac{\partial}{\partial\alpha}q_2 - q_1c'(\alpha). \tag{A5}$$

Incorporating equation (A4) and the fact that one can write

$$\Delta q_2 = -\alpha\int_{\theta_1'}^{\bar{\theta}}\left[F_2(p_2 \mid \theta) - F_2(p_2-\tau \mid \theta)\right]dF_1(\theta)$$

allows equation (A5) to be written as

$$\frac{\partial\Pi}{\partial\alpha} = -\frac{1}{\alpha}\Delta\Pi + q_1[\beta c_2 - c'(\alpha)].$$

Because this derivative equals zero at the optimum, and $[\beta c_2 - c'(\alpha)]$ is decreasing and crosses zero once at $\alpha_{\min}$, the result follows. In particular, if $\Pi^*(0) - \Pi^*(\tau) < 0$, then $\Delta\Pi < 0$ at a supposed optimum, implying $\alpha > \alpha_{\min}$. Instead, if $\Delta\Pi > 0$, then it must be that $\alpha < \alpha_{\min}$.

Proof of Proposition 4. To prove this, I first compute the relevant derivative for the monopolist and then for the social planner. Comparison of the two implies the result.

Because q_1 and Q are fixed, changes in α influence p_1, p_2, and q_2. Using the constraint that $q_2 = Q - \alpha q_1$, the definition of p_1 from equation (1), and the envelope theorem applied to V^+ and V^-, the following emerges, where all derivatives refer to changes in the relevant variables or functions fixing q_1 and Q.

$$\frac{d\Pi}{d\alpha} = q_1\left(\frac{dp_1}{d\alpha} - c'(\alpha)\right) + \beta\frac{dq_2}{d\alpha}(p_2 - c_2) + \beta q_2\frac{dp_2}{d\alpha}$$
$$= \beta q_1\left\{-\tau F(p_2-\tau) + p_2 + \int_{p_2-\tau}^{p_2}(\theta - p_2)dF(\theta) + \alpha\frac{dp_2}{d\alpha}[1-(F(p_2)-F(p_2-\tau))]\right\}$$
$$-q_1c'(\alpha) - \beta q_1(p_2 - c_2) + \beta q_2\frac{dp_2}{d\alpha}$$
$$= -q_1c'(\alpha) + \beta q_1\left\{-\tau F(p_2-\tau) + \int_{p_2-\tau}^{p_2}(\theta - p_2)dF(\theta) + c_2\right\}$$
$$+\beta\frac{dp_2}{d\alpha}\left\{q_2 + \alpha q_1[1-(F(p_2)-F(p_2-\tau))]\right\}.$$

Now consider social welfare W, given by

$$W = \int_{\theta_1'}^{\bar{\theta}} \theta dF(\theta) - q_1 c(\alpha) + \beta \alpha q_1 \left[-\tau F(p_2 - \tau) + \int_{p_2-\tau}^{p_2} \theta dF(\theta) \right] + \beta \int_{p_2}^{\bar{\theta}} \theta dF(\theta) - \beta c_2 q_2.$$

The change in W from an increase in α is

$$\begin{aligned}
\frac{dW}{d\alpha} &= -q_1 c'(\alpha) + \beta q_1 \left[-\tau F(p_2 - \tau) + \int_{p_2-\tau}^{p_2} \theta dF(\theta) + c_2 \right] \\
&\quad + \beta p_2 \frac{dp_2}{d\alpha} [f(p_2)(\alpha q_1 - 1) - \alpha q_1 f(p_2 - \tau)] \\
&= -q_1 c'(\alpha) + \beta q_1 \left[-\tau F(p_2 - \tau) + \int_{p_2-\tau}^{p_2} \theta dF(\theta) + c_2 \right] - \beta p_2 q_1 [F(p_2) - F(p_2 - \tau)] \\
&= -q_1 c'(\alpha) + \beta q_1 \left[-\tau F(p_2 - \tau) + \int_{p_2-\tau}^{p_2} (\theta - p_2) dF(\theta) + c_2 \right],
\end{aligned}$$

where the second-to-last equality comes from using the implicit function theorem on equation (2) to derive $dp_2/d\alpha$, keeping in mind that Q is fixed during the derivation.

Finally, comparison of $dW/d\alpha$ and $d\Pi/d\alpha$ shows that $d\Pi/d\alpha$ is larger by the term

$$\beta \frac{dp_2}{d\alpha} \{q_2 + \alpha q_1 [1 - (F(p_2) - F(p_2 - \tau))]\}.$$

Because $Q = \alpha q_1 + q_2 \geq q_1$ by assumption, $q_2 \geq 0$, and thus the sign of this term is the same sign as $dp_2/d\alpha$, which is positive (using the implicit function theorem as just mentioned) so long as τ is positive but zero otherwise. Because this is true for any vector of controls, not just at the optimum, the result follows.

Proof of Proposition 5. That $\tau^* \in \{0, \infty\}$ follows from the observation that, because there are essentially two types in the second period, raising τ lowers profits until the point at which trade actually shuts down, at which point profits might jump, and that past that point further increases have no effect.

To prove the rest of the proposition, first suppose that $c > \theta$, so that it is never optimal to produce units in period two. In this case, closed markets means that $p_1 = \theta + \beta\rho\theta$ and profits are $p_1 - c$. Instead, having open markets means that $p_1 = \theta + \beta\theta$ and units are traded from cohort one consumers to cohort two consumers in period two. Clearly, for $c > \theta$, profits are higher under open markets.

Now suppose instead that $c < \theta$. Under closed markets it must be optimal to sell to cohort two consumers at price $p_2 = \theta$ (doing so provides a zero value of waiting to cohort one consumers in period one and hence does not limit the firm's ability to extract rent). The highest the firm can charge in period one is $p_1 = \theta + \beta\rho\theta$ and hence profits are

$$(\theta + \beta\rho\theta - c) + \beta(\theta - c). \tag{A6}$$

Consider instead open markets. If the firm chooses to set p_2 such that all consumers hold units in period two, then $p_2 = \rho\theta$ and $p_1 = \theta + \beta\rho\theta$ and profits are

$$(\theta + \beta\rho\theta - c) + \beta(\rho\theta - c). \tag{A7}$$

Comparing profits in (A6) to (A7), it is clear that closed markets are better than ensuring that all consumers hold units in period two with open markets. Hence, consider instead setting a price $p_2 = \theta$ under open markets, implying $p_1 = \theta + \beta\theta$ and entailing production only in the first period for profits of

$$\theta + \beta\theta - c. \tag{A8}$$

Comparing (A6) to (A8), and given what has already been shown, open markets are better if and only if $c > \rho\theta$.

Proof of Proposition 6. Sufficiency has been proven in the text, and so consider necessity. Define $\theta_F^* = \arg\max_\theta \theta(1 - F(\theta))$ and $\theta_G^* = \arg\max_\theta \theta(1 - G(\theta))$, and suppose that $\theta_F^* \geq \theta_G^*$, and $\tau = \tau^* > 0$ is strictly optimal. In the proof of Proposition 1, I showed that, in the case of no new consumer entry, one could use the transformations $\tilde{\theta}_1 = \theta_1'$, $\tilde{\theta}_2 = \theta_2' - \tau$, and $\tilde{\theta}_3 = \theta_2'$, and write profits as

$$-\beta\alpha\tau(F(\tilde{\theta}_2) - F(\tilde{\theta}_1)) + \tilde{\theta}_1(1 - F(\tilde{\theta}_1)) + \beta\alpha\tilde{\theta}_2(1 - F(\tilde{\theta}_2)) + \beta(1 - \alpha)\tilde{\theta}_3(1 - F(\tilde{\theta}_3)).$$

With an additional cohort, actual profits are simply the above, plus $\beta\tilde{\theta}_3(1 - G(\tilde{\theta}_3))$. Consider maximizing these total profits but neglecting (for the moment) the term $-\beta\alpha\tau(F(\tilde{\theta}_2) - F(\tilde{\theta}_1))$. That is, consider maximizing

$$\tilde{\theta}_1(1 - F(\tilde{\theta}_1)) + \beta\alpha\tilde{\theta}_2(1 - F(\tilde{\theta}_2)) + \beta(1 - \alpha)\tilde{\theta}_3(1 - F(\tilde{\theta}_3)) + \beta\tilde{\theta}_3(1 - G(\tilde{\theta}_3)), \tag{A9}$$

subject, of course, to the constraints $\tilde{\theta}_1 \leq \tilde{\theta}_2 \leq \tilde{\theta}_3$; observe that this allows the firm to also select frictions τ. Note that for any given $\tilde{\theta}_3$, quasiconcavity of $\theta(1 - F(\theta))$ ensures that the firm optimally sets $\tilde{\theta}_1 = \tilde{\theta}_2$. This means that the neglected term $-\beta\alpha\tau(F(\tilde{\theta}_2) - F(\tilde{\theta}_1))$ in the actual profit function is automatically maximized when one ignores it, and hence the solution of the auxiliary function above coincides with the solution to the actual program; thus I will henceforth focus only on this auxiliary function.

Quasiconcavity also implies that if $\tilde{\theta}_3 \leq \theta_F^*$, then it must be that $\tilde{\theta}_1 = \tilde{\theta}_2 = \tilde{\theta}_3$. If this last equality held at the optimum, then by the definition of $\tilde{\theta}_2$ and $\tilde{\theta}_3$ it follows that $\tau^* = 0$. Thus, if it can be shown that the maximum cannot exhibit $\tilde{\theta}_3 > \theta_F^*$, the proposition follows. Suppose $\tilde{\theta}_3 > \theta_F^*$. Then, $\tilde{\theta}_1 = \tilde{\theta}_2 = \theta_F^*$, because this is feasible and clearly maximizes the first two terms of equation (A9). But because $\theta_F^* \geq \theta_G^*$ by assumption, quasiconcavity implies that the third and fourth terms of equation (A9) could be raised by lowering $\tilde{\theta}_3$ to θ_F^*. Hence, it must be that $\tilde{\theta}_3 \leq \theta_F^*$ at the optimum, a contradiction that establishes the result.

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