Competition, Monopoly Maintenance, and Consumer Switching Costs

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November 2006

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by

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November 2006

*We would like to thank Dennis Carlton, Michael Conlin, Joe Harrington, George Hay, Robert Masson, Yossi Spiegel, and seminar participants at the Australian National University, Cornell University, the Federal Trade Commission, UCLA, the University of Delaware, the University of Melbourne, the University of New South Wales, and the U.S. Justice Department for helpful comments. We would also like to thank Jonathan Lim, Joe Podwol, and Kameshwari Shankar for research assistance.

ABSTRACT

Significant attention has been paid to why a durable-goods producer with little or no market power would monopolize the maintenance market for its own product. This paper provides an explanation for this practice that is based on consumer switching costs and the choice of consumers between maintaining and replacing used units. In our explanation, if a firm does not monopolize the maintenance market for its own product, then consumers sometimes maintain used units when it would be efficient for the units to be replaced. In turn, the return to monopolizing the maintenance market is that the practice allows firms to avoid this inefficiency. An interesting aspect of our analysis that has significant public-policy implications is that, in contrast to most previous explanations for why a durable-goods producer with little or no market power would monopolize the maintenance market for its own product, in our explanation the practice increases rather than decreases both social welfare and consumer welfare.

I. INTRODUCTION

In a number of court cases there have been allegations that various firms such as Kodak, British Leyland, and General Electric have monopolized the aftermarkets for their own products.[1] A typical allegation is that the durable-goods producer monopolizes the maintenance aftermarket by refusing to sell spare parts to alternative maintenance suppliers with the result that consumers of the firm's products have no option but to purchase maintenance from the original durable-goods producer. In this paper we explore an explanation for this practice that is based on consumer switching costs and the choice of consumers between maintaining and replacing used units. In particular, we show that the practice can be used by firms to avoid an inefficiency concerning consumer maintenance decisions, where, in contrast to most previous analyses of the issue, in our analysis the practice increases both social welfare and consumer welfare. This finding has important implications for public policy as elaborated upon below.

Much of the attention to this issue stems from the 1992 U.S. Supreme Court decision in the case *Eastman Kodak Company v. Image Technical Services, Inc., et al*. Consistent with the above discussion, in that case Kodak was alleged to have monopolized the maintenance market for its copiers and micrographic equipment by refusing to sell spare parts to alternative maintenance suppliers. The Supreme Court ruled that, even if Kodak had no market power in the market for new equipment, a potentially relevant antitrust concern was Kodak's behavior in the maintenance market for its own products. The Court thus concluded that Kodak's alleged behavior of monopolizing the maintenance market for its own products by refusing to sell spare parts to alternative maintenance suppliers was at least a potential antitrust violation. This Court decision has significant implications for antitrust policy in aftermarkets and as a result has attracted substantial attention.

This paper investigates from a theoretical standpoint the U.S. Supreme Court's ruling that, even when a firm has little or no market power in the market for new units, a firm's behavior in the maintenance market can constitute an antitrust violation. We consider an infinite-period competitive durable-goods model in which new consumers enter the market in each period and in which a unit of

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[1] These cases include the U.S. cases *Eastman Kodak Company v. Image Technical Services*, *Inc., et al.*, 1992, *Service & Training Inc. v. Data General Corporation*, 1992, *PSI Repair Service, Inc. v. Honeywell, Inc.*, 1997, *United States of America v. General Electric Company*, 1999, and *SMS Systems Maintenance Services, Inc. v. Digital Equipment Corporation*, 1999, as well as the U.K. cases *British Leyland Motor Corporation Ltd. v. Armstrong Patents Company Ltd.*, 1986, and *British Leyland Motor Corporation Ltd. v. T.I. Silencers Ltd.,* 1987, and the Hong Kong case *Cannon Kabushiki Kaisha v. Green Cartridge Company*, 1999. For a more complete list of U.S. cases see Elzinga and Mills (2001).

output potentially lasts two periods, where an important aspect of the model is that the required level of maintenance for a used unit is stochastic. Our model incorporates two of the main features of the *Kodak* case and a number of other cases in which monopolizing the maintenance market has been alleged. First, each durable-goods producer has the option of monopolizing the maintenance market for its own product. By this we mean that in each period, each durable-goods producer has the option of becoming the sole supplier of maintenance for its own new and used units of output. Second, the market for new units is characterized by consumer switching costs.[2] Due to switching costs, a firm that sells new units in period t has market power in subsequent periods when selling new units to those period-t purchasers. An important focus of our analysis is to explore the ramifications of this market power on the efficiency of competitive maintenance markets.[3]

Analysis of this model yields a number of interesting findings. First, if the maintenance market is competitive and durable-goods producers cannot commit to future prices for new units, then both social welfare and consumer welfare are below the levels achieved when commitment is possible. The logic for this result is as follows. If a firm could commit to future new-unit prices, then when selling a new unit to a new consumer in period t the firm would commit to sell replacement units in future periods to this consumer at marginal cost. The reason is that this results in consumers making efficient choices

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[2] As indicated, a key component of our argument is the presence of consumer switching costs. This is reasonable to the extent that the real-world cases we are trying to capture are characterized by substantial consumer switching costs. A number of the cases, including the *Kodak* case, discuss the idea that consumers faced substantial switching costs. For example,

> "The system at CSC includes a combination of micrographics machines, and of computer hardware and software tailored specifically to CSC's needs. Trading its entire equipment for an "interbrand" competitor of Kodak, due to supra-competitive prices, it would be financially unfeasible for CSC. The special software would have to be retailored at a cost of several hundred thousand dollars. Data would have to be reformatted and operators would have to be retrained, again, at a cost of hundreds of thousands of dollars..."
>
> (Plaintiff's Memorandum in *Eastman Kodak Co. v. Image Technical Services, Inc., et al.* (1992), pp. 19-20)

The allegations in the *Kodak* case also state that similar systems to the one described above were true for a variety of the firm's customers such as "Blue Cross/Blue Shield, insurance companies, banks, and other large financial institutions in many states." (Plaintiff's Memorandum in *Eastman Kodak Co. v. Image Technical Services, Inc., et al.* (1992), p. 19)

[3] There is an extensive literature that investigates models characterized by consumer switching costs. However, the existing literature does not consider the idea that switching costs in a competitive durable-goods industry can affect the efficiency of maintenance decisions. Papers in this literature include Klemperer (1987,1989) and Farrell and Shapiro (1988). See Klemperer (1995) for a survey.

concerning whether to maintain or replace used units. However, if firms lack the ability to commit, then due to the switching costs the firm extracts surplus in these later periods by charging prices for replacement units that are above marginal cost. The result is that, since maintenance is priced competitively while prices for replacement units are above the competitive price, consumers in these later periods sometimes maintain used units when it would be efficient for the units to be replaced.

Our second finding is that, if each durable-goods producer has the option of monopolizing the maintenance market for its own product, then each firm monopolizes the maintenance market in each period and in this way avoids the inefficiency described above, i.e., both social welfare and consumer welfare increase. To see the logic for this result consider a durable-goods producer that monopolizes the maintenance market for its own product every period. In each period, by optimally setting the prices for replacement units and the price schedule associated with different levels of maintenance, the firm extracts all the surplus from the consumers who purchased new units from the firm in the past (there is surplus both because of switching costs and because a used unit may require little maintenance). In turn, since in each period the firm is extracting all of the surplus, the firm has an incentive to behave in a manner that maximizes that surplus. The result is that consumers efficiently choose whether to maintain or replace used units, and, since in a competitive market it is the consumers who capture any increase in social welfare, there is a corresponding increase in both consumer and social welfare.

In addition to the two main results discussed above, we also derive a number of other results of interest. One such result concerns the role of no-trade clauses in maintenance contracts which is a common feature in many durable-goods markets. In particular, in our analysis use of these no-trade clauses allow a firm to more effectively price discriminate by preventing the resale of new and used durable units. We show that, in the presence of learning-by-doing in the production of durable units, this enhanced ability to price discriminate improves efficiency by increasing the number of new units produced at a low rather than high marginal cost of production.

Other interesting results are found in two extensions of our basic analysis. Our first extension considers why firms might prefer to monopolize the maintenance markets for their own products rather than sign long-term contracts that specify the future prices for replacement units. Here we show that, if we incorporate into the model the realistic enrichment that there is asymmetric information concerning an endogenous durability choice, then the resulting moral-hazard problem causes maintenance-market monopolization to be preferred over long-term contracting. Our second extension considers why a firm

might prefer to monopolize the maintenance market for its own products by refusing to sell spare parts to alternative maintenance suppliers rather than simply raise the price for those spare parts. Here we show that maintenance-market monopolization gives the firm more control over the price of maintenance with the result that monopolization is preferred because it is more effective at eliminating the maintenance versus replacement distortion.

Most previous researchers who have modeled a competitive durable-goods producer that monopolizes the maintenance market for its own product argue that the behavior reduces social welfare because it causes a standard deadweight loss due to monopoly pricing in the maintenance market (see the discussion in Section IV and earlier discussions in Shapiro (1995) and Chen, Ross, and Stanbury (1998)). Our analysis shows that there is another possibility for what happens when a competitive durable-goods producer monopolizes the maintenance market for its own product. That is, the behavior can serve to eliminate a social-welfare distortion present in the maintenance market due to consumer switching costs. From a public-policy perspective this is a crucial difference because, if the main result of the behavior is the elimination of a social-welfare distortion present in the maintenance market, then the behavior will increase rather than decrease social welfare in which case the behavior should be allowed. We discuss the public-policy implications of our analysis in detail in Section IV.

Another interesting aspect of our analysis is that it shows that time inconsistency can be important in competitive durable-goods markets. Building on the initial insights of Coase (1972) and Bulow (1982), earlier literature on durable-goods markets focuses on monopoly models.[4] We show, however, that time inconsistency can also be important in competitive durable-goods settings when switching costs are important. Further, in addition to showing that time inconsistency can be important in such settings, we also show that the ramifications of time inconsistency are quite different in these competitive settings. That is, whereas time inconsistency hurts firm profitability in monopoly durable-goods settings, it is the consumers rather than the producers who are hurt by time inconsistency in our competitive durable-goods analysis.

Our results build on insights found in earlier papers such as Schmalensee (1974), Su (1975), and Rust (1986). Schmalensee, Su, and Rust consider durable-goods-*monopoly* settings in which the

[4] Other papers in this literature include Bulow (1986), Ausubel and Deneckere (1989), Butz (1990), Waldman (1993), and Karp and Perloff (1996). For a survey of durable-goods theory that discusses this literature see Waldman (2003).

maintenance market is competitive. They show that, because the durable-goods monopolist employs above marginal-cost pricing, consumers sometimes maintain used units when it would be efficient for the consumers to purchase new units. Our analysis first shows that this earlier result of Schmalensee, Su, and Rust extends to a setting in which the market for new units is *perfectly competitive* and there are consumer switching costs that create market power at the date a consumer chooses whether to maintain or replace a used unit. This market power induces consumers to sometimes make inefficient choices concerning whether to maintain or replace used units. A fundamentally new insight of our analysis is our demonstration that, as discussed above, this inefficiency can be avoided by allowing competitive durable-goods producers to monopolize the maintenance markets for their own products, where both social welfare and consumer welfare increase as a consequence.[5]

The outline for the paper is as follows. Section II demonstrates our basic result that monopolizing the maintenance market can be employed in a competitive durable-goods setting to avoid a distortion concerning the maintenance versus replacement decision. Section III investigates the robustness of our results to two extensions of our basic model. The first introduces the possibility of long-term contracts that specify future prices for new durable units, while the second asks whether raising the price for spare parts can be used as a substitute for monopolizing the maintenance market. Section IV first compares and contrasts our explanation for maintenance-market monopolization with alternative explanations found in the literature and then discusses the antitrust implications of our analysis. Section V provides concluding remarks.

II. MONOPOLY MAINTENANCE AND CONSUMER SWITCHING COSTS

In this section we demonstrate our main result that, in the presence of consumer switching costs, a competitive durable-goods producer can avoid inefficient consumer behavior by monopolizing the

[5] Our paper is also related to an analysis that appears in Carlton and Waldman (2006). That paper focuses on the idea that competitive aftermarkets are not always efficient, where one of the cases analyzed is the same basic setting analyzed here. However, we analyze this setting in much more detail than do Carlton and Waldman. For example, they consider a two-period setting while we consider an infinite-period setting with overlapping generations of consumers. This allows us to address the role of no-trade clauses in maintenance contracts which, as indicated, is an important feature of real-world durable-goods markets. Also, we show that by incorporating endogenous durability choice maintenance-market monopolization can be preferred to long-term contracting, and we further show why maintenance-market monopolization can be preferred to raising the price for spare parts. See also Tirole's (1988) textbook for a reader exercise in which a durable-goods monopolist increases its profits by monopolizing the maintenance market because the monopolization avoids the Schmalensee, Su, and Rust distortion.

maintenance market for its own product. We also show the role of no-trade clauses in maintenance contracts in achieving efficient outcomes. In the next section we explore the robustness of our analysis by considering two extensions.

A) The Model

We consider an infinite-period model in which there are two perfectly-competitive industries, where one produces a durable good that lasts two periods while the other supplies maintenance for this good. A newly produced unit is referred to as a new unit while one that is one period old is referred to as used. We further assume a simple type of learning-by-doing on the part of durable-goods producers. Each durable-goods producer has a constant marginal cost of production equal to c and no fixed costs in any period for which the firm produced a strictly positive amount of output in the past, while marginal cost equals c', $c'>c$, if this is the first period with positive production. Further, to simplify the statement of the results we consider the nature of equilibrium in the limit as c' approaches c from above. Incorporating the learning-by-doing assumption rules out as equilibria outcomes that have the unrealistic feature that each cohort of consumers purchases durable units from a different set of durable-goods producers. We discuss this in detail at the end of the next subsection.

We now turn to our assumptions concerning maintenance. A new unit of output requires a fixed amount of maintenance that we denote m^N, $m^N>0$, while the amount of maintenance required by a used unit, denoted m^U, is stochastic and is described further below. We also assume that new and used units are perfect substitutes as long as they each receive at least the required level of maintenance. Further, a unit, either new or used, that receives less than the required level of maintenance cannot be used for consumption and has a scrap value equal to zero.

The level of maintenance required by a used durable unit produced by any firm j is the realization of a random draw from the probability density function f(.), where $f(m^U)>0$ for all $m^U \in (0,\infty)$.[6] We also assume that the realization of m^U for any specific used unit is privately observed by the individual who consumed the unit when it was new, where m_{it}^U denotes the level of maintenance required

[6] We also assume f(.) is such that when the maintenance market is competitive and firms cannot commit to future prices, there is a unique price for a new unit that replaces a used unit that maximizes the present discounted value of future profits. Note, this assumption is not crucial but serves to simplify both the statements of the propositions and the proofs.

in period t by the used unit consumed as new in period t-1 by individual i.[7] By making the realistic assumption that the required level of maintenance is stochastic, we capture the idea discussed above that when replacement units are priced above marginal cost an inefficiency arises in which too many used units are maintained rather than replaced.

Maintenance for a durable unit produced by firm j can be supplied either by a firm in the perfectly-competitive maintenance industry or by firm j itself, where each type of firm has no fixed costs of supplying maintenance while the variable costs of supplying maintenance of level m equal m. Note, since the maintenance industry is perfectly competitive, firms in this industry are willing to sell maintenance of level m at a price equal to m. We allow for two possibilities concerning the maintenance market. We first assume that each durable-goods producer cannot stop consumers of the firm's product from purchasing maintenance from firms in the competitive maintenance industry. We then assume that each durable-goods producer can stop consumers of its product from purchasing maintenance from competitive maintenance sellers and in this way monopolize the maintenance market for its own product. Although at this point we are not specific concerning exactly how this aftermarket monopolization is achieved, our reading of the literature is that in most real-world cases this is achieved by the durable-goods seller refusing to sell proprietary parts to alternative maintenance suppliers. We come back to this issue in Section III.B.

A related assumption is that when a durable-goods producer sells maintenance for its own product we assume it has the option of including a no-trade clause in the sale. The no-trade clause means that a consumer who purchases maintenance from a firm cannot sell the maintenance to another consumer on the secondhand market. As indicated earlier, such no-trade clauses are common in real-world maintenance markets. In the photocopier market, for example, Xerox maintenance contracts are in

[7] One way to justify m_{it}^U being privately observed by consumer i is by assuming that m_{it}^U is a function of the number and severity of the machine's random malfunctions when it was new, and the only individual who has direct knowledge of this is consumer i. In this interpretation the stochastic variable is the number and severity of malfunctions when the unit was new. In the presence of asymmetric information concerning m_{it}^U, a durable-goods producer cannot make the replacement-unit price it offers a consumer contingent on the consumer's realization for m_{it}^U, and this, in turn, limits a durable-goods producer's ability to price discriminate if it does not monopolize the maintenance market for its own product. Note, the alternative assumption that a unit's original producer acquires some knowledge concerning the realization of m_{it}^U but less precise information than consumer i would not change the qualitative nature of the results. Also, the assumption that m_{it}^U can be observed precisely by the unit's original producer when that producer monopolizes the maintenance market for its own product would also not change the qualitative nature of the results.

general not transferable. This is also true for Business Methods Inc. which is an authorized dealer of Toshiba copiers.[8]

If durable-goods producer j does not monopolize the maintenance market for its own product in either period t-1 or t, then it can charge two prices for new units in period t. P_{jt1}^{C} denotes the price the firm charges consumers who do not trade in a used unit produced by firm j, while P_{jt2}^{C} denotes the price the firm charges consumers who trade-in a used unit produced by firm j. In both cases the superscript C refers to the fact the maintenance market is competitive.[9] Also, we restrict P_{jt2}^{C} to be less than or equal to P_{jt1}^{C} since, if $P_{jt2}^{C}>P_{jt1}^{C}$, the firm would sell no units at P_{jt2}^{C} because consumers with used units produced by firm j would always choose to purchase at the no-trade-in price P_{jt1}^{C}.

In contrast, suppose durable-goods producer j monopolizes the maintenance market for its own product both in t-1 and t, and in each period it includes a no-trade clause in its sales of maintenance. This allows the firm to charge the following three prices for new units in period t. P_{jt1}^{M} denotes the price the firm charges consumers who did not consume a unit of the firm's product in the previous period. P_{jt2}^{M} denotes the price the firm charges consumers who consumed one of the firm's new units in the previous period. P_{jt3}^{M} denotes the price the firm charges consumers who consumed one of the firm's used units in the previous period. In all three cases the superscript M refers to the fact the maintenance market is monopolized. In other words, the difference between this case and the previous one is that here a firm can price discriminate between an individual who consumed one of the firm's used units in the previous

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[8] We also attempted to find out this information for Kodak, but were unable to acquire the information from a Kodak representative. Besides the fact that they are common in practice, the reason we feel it is realistic to assume a durable-goods producer can include no-trade clauses when it sells maintenance is that maintenance consists of servicing a durable unit at regular intervals and when the unit malfunctions. In other words, for the case of maintenance no-trade clauses are feasible since they are easy to monitor and enforce. In contrast, we feel it is not realistic to allow no-trade clauses when a firm sells a durable unit (in particular, when it sells the unit in the absence of monopolizing the maintenance market) because monitoring and enforcing a no-trade clause in that case would be quite difficult.

[9] To be precise, the firm can theoretically price discriminate across three groups of consumers in this case, i.e., consumers who do not trade-in used units produced by firm j, consumers who trade-in functional used units produced by firm j, i.e., one-period-old used units, and consumers who trade-in non-functional used units produced by firm j, i.e., two-period or older used units. However, what happens in equilibrium is that the firm would like to charge the lowest price to the consumers who do not own either type of used unit at the beginning of a period, but incentive compatibility yields that the firm cannot charge a lower price to this group, i.e., if it did, all three groups would purchase at this lower price. The result, in turn, is that restricting the firm to only offer the two prices that we posit is equivalent to allowing the firm to offer three prices. Note also that we could allow the firm to charge different prices to customers who trade-in a used unit produced by a different firm, but this would also not change the results.

period and an individual who in the previous period did not consume either a new or used unit of the firm's output.

The reason monopolizing the maintenance market with no-trade clauses included in its sales of maintenance allows firms to price discriminate across these three groups is as follows. On the one hand, the firm can identify who is in which group in period t because it monopolized the maintenance market in period t-1 and through the act of providing maintenance directly observed who is in which group. On the other hand, the firm can prevent resale of its new durable units across these three groups by only selling maintenance to purchasers of new durable units and individuals who own the firm's used units. This prevents resale of the firm's new durable units because the firm is the sole provider of maintenance for these units, the maintenance is non-transferable, and the units are worthless without maintenance.[10]

On the demand side, we assume that in each period t, $t=1,2,...\infty$, a continuum of nonatomic consumers whose total mass equals n_t, $n_t>0$, is born and lives forever, where $\sum_{t=1}^{\infty} n_t<\infty$. We say that a consumer who was born in period t is of age $t'-t+1$ in period t', $t'\geq t$. We further assume that consumers are heterogeneous in terms of their basic valuations for the durable product and that there are consumer switching costs.[11] The specification for consumer utility in the period a consumer is born is simple. In particular, in the period in which he or she is born, each consumer i receives a gross benefit equal to v_i from consuming a new durable unit produced by any of the durable-goods producers that receives at least m^N units of maintenance. Further, the distribution of v_is in the cohort of consumers born in any period t is described by a density function $h_t(v)=n_t g(v)$, where $g(v)>0$ for all $(0,V]$, $g(v)=0$ for all v outside of this interval, and $V>c+m^N$. Note that in the analysis that follows it does not matter whether each individual i's value for v_i is privately known by individual i or publicly observable.

The specification for consumer utility in subsequent periods is more complicated because it

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[10] If the firm monopolizes the maintenance market in periods t-1 and t but does not include a no-trade clause in its period-t sales of maintenance, then the firm can identify the three groups in period t but cannot prevent resale across the three groups.

[11] As discussed by Klemperer (1995), there are a number of factors that can lead to the presence of consumer switching costs. One possibility that nicely fits our model is that there is a cost associated with learning how to operate any particular producer's product. That is, each product is somewhat idiosyncratic concerning the specifics of its operation, and as a result a consumer bears a learning cost in the first period he or she uses a particular producer's product. The result is that in the first period a consumer is in the market he or she will bear this cost independent of which product he or she consumes. However, the consumer can avoid the cost in all later periods by always consuming a unit produced by the same firm that produced the unit he or she consumed in the first period.

captures the switching costs. Let Δ, $\Delta>0$, denote the size of the switching costs and let firm j_{it} be the producer of the durable unit that was consumed by individual i in period t. Given this, consider consumer i born in period t and a period t′, t′>t. The consumer receives a gross benefit equal to $v_i+\Delta$ from consuming either a new or a used durable unit produced by firm $j_{it'-1}$ and the required level of maintenance. On the other hand, the consumer receives a gross benefit equal to v_i from consuming a new or a used unit produced by a firm other than $j_{it'-1}$ and the required level of maintenance. If consumer i did not consume a durable unit in the previous period, then the consumer receives a gross benefit equal to v_i from consuming a new or a used unit produced by any manufacturer and the required level of maintenance. It is also assumed that all firms and all consumers are risk neutral and have a discount factor β, $0<\beta<1$.

The timing of events is as follows. Each period consists of four stages. First, when monopolizing the maintenance market is an option, each durable-goods producer decides whether in that period to allow competition or monopolize the maintenance market for its own product. Further, if a firm monopolizes the maintenance market, it decides whether to include a no-trade clause in its sales of maintenance.[12] Second, each durable-goods producer chooses the prices for new units of output. At the same time, each durable-goods producer that has chosen to monopolize the maintenance market chooses how much to charge for m^N units of maintenance to individuals who purchase new units of its output, and a price schedule that specifies a price for each level of used-unit maintenance in the interval $(0,\infty)$. We also assume all prices are non-negative. Third, each consumer makes his or her purchase decisions. Fourth, a secondhand market opens up in which prices equate supply and demand. Note that in equilibrium there is never trade on the secondhand market, but introducing the secondhand market allows us to show the role played by no-trade clauses in sales of maintenance.

Finally, to simplify the analysis, we focus on equilibria in which contracting and trading options are stationary, i.e., equilibria in which each firm offers the same set of contracts in each period and in which each market price is invariant to time, except we allow $P_{jt1}{}^C$ to have different values before and after a firm first sells new units. Furthermore, to simplify the exposition, we eliminate from consideration

[12] An alternative assumption that would yield the same overall results is that, in a period in which a firm first sells new units, the firm has the option of committing to monopolize the maintenance market and include a no-trade clause in its sales of maintenance in all subsequent periods. Also, when a firm includes a no-trade clause in its sales of maintenance in period t, we also assume the firm can choose to only sell maintenance in period t to consumers who purchased new durable units from the firm in either period t or t-1.

equilibria in which firms offer terms that will not be accepted and incorporate an ε transaction cost associated with trading on the secondhand market (this last assumption rules out equilibria characterized by trades on the secondhand market that do not strictly improve welfare).

B) Analysis

The outline for this section is as follows. First, we discuss the results of a benchmark analysis in which the maintenance market is competitive and each durable-goods producer can commit in the first period to the prices it will charge in subsequent periods for a new unit of output. Second, we show that inefficiencies arise when commitment is not possible and durable-goods producers do not have the option of monopolizing the maintenance market for their own products. Third, we show that monopolizing the maintenance market allows firms to avoid these inefficiencies with the result that both social welfare and consumer welfare increase.

Suppose the maintenance market is competitive and each durable-goods producer can commit in the first period to the prices it will charge in subsequent periods for a new unit of output. Let P_{jt1}* denote the price that producer j charges in this case for a new unit of output in period t to consumers without a trade-in, while P_{jt2}* denotes the price that producer j charges for a new unit of output in period t to consumers who trade-in a used unit produced by firm j. There exist values v_L*, $0<v_L*<V$, and m*, $0<m*<\infty$, such that the following describes the equilibrium. First, each producer j chooses $P_{jt1}*=c$ for all t, $t=1,2,...\infty$ and $P_{jt2}*=c$ for all t, $t=2,3,...\infty$. Second, every consumer i born in period t, $t=1,2,...\infty$, for whom $v_i>v_L*$ purchases a new unit in period t and a new unit from firm j_{it} in every period t′, $t'=t,t+1,...\infty$, in which the consumer does not own a used unit at the beginning of the period, while consumers born in t for whom $v_i\leq v_L*$ never purchase new units. Third, in any period t in which consumer i owns a used unit at the beginning of the period, the consumer maintains the unit if $m_{it}^U\leq m*$ and purchases a new unit if $m_{it}^U>m*$.[13] Fourth, in any period t in which individual i consumes a new unit the individual purchases m^N units of maintenance from a competitive maintenance seller, while in any period t in which individual i consumes a used unit the individual purchases m_{it}^U units of maintenance. Fifth, no firm starts production after the first period.

[13] Throughout the analysis we assume that a consumer who is indifferent between maintaining and replacing a used unit chooses to maintain it. Further, a consumer who is indifferent between purchasing a new unit and consuming nothing chooses to consume nothing. Neither assumption is essential but rather both serve to simplify the descriptions of equilibrium behavior.

The logic behind the above equilibrium is as follows. Consider the cohort of consumers born in the first period. Because it is a competitive market, each durable-goods producer that sells a strictly positive number of new units to this cohort of consumers in the first period must market its product in the manner that minimizes the inefficiency associated with consuming the product. This means that each such firm commits to charge c for new units to consumers both with and without trade-ins in all subsequent periods. The reason is that, if maintenance and new units are both priced at marginal cost in all subsequent periods, the consumers will make efficient choices concerning who to purchase replacement units from and when to maintain rather than replace used units. Further, since the price for a new unit in each subsequent period is c, the zero-profit condition associated with perfect competition yields that the first-period price also equals c.[14] In turn, repeating this argument for each cohort of consumers yields that all units in all periods are sold at a price equal to c. Finally, no firm starts production after the first period because learning-by-doing yields that it is less expensive for cohorts born after the first period to buy new units from firms that started production earlier.

We now turn our attention to what happens when the maintenance market is competitive and each durable-goods producer is not able to commit in the first period to the prices it will charge in subsequent periods for a new unit of output. Below EU_i^C denotes the present discounted value evaluated in the period the consumer is born of the expected net benefits received by consumer i in this case, while EU_i^* denotes the present discounted value evaluated in the period the consumer is born of the expected net benefits received by consumer i in the benchmark case.

Proposition 1: Suppose the maintenance market is competitive. If each firm cannot commit in the first period to the prices it will charge in subsequent periods for a new unit of output, then every equilibrium is characterized by values v_L^C, $v_L^* < v_L^C < V$, and m^C, $m^C > m^*$, such that i) through vi) describe the equilibrium.[15]

i) For every firm j and period t such that the firm first sells new units in period t, $P_{jt1}^C = P' < c$,

[14] To be precise, the zero-profit condition yields that the first-period price equals c′ which we denote as c since we focus on the nature of equilibrium in the limit as c′ approaches c from above. Similarly, the critical value for v_i for consumers born in period 1 is higher than v_L^* but we write it as v_L^* since again we focus on the nature of equilibrium in the limit as c′ approaches c from above. We employ similar transformations in later results.

[15] There are multiple equilibria because, for example, how many firms start selling in each period is not uniquely defined.

while $P_{jt1}^{C}=P'+\Delta$ for every firm j and period t such that the firm sold new units prior to t.

ii) For every firm j and period t, $P_{jt2}^{C}=P''$, $c<P''\leq P'+\Delta$.

iii) Each consumer i born in period t for whom $v_i>v_L^{C}$ ($v_i\leq v_L^{C}$) purchases a new unit in period t from a firm that first sells new units in that period and m^N units of maintenance from a competitive maintenance seller (never purchases new units, used units, or maintenance).

iv) In each period t′, t′>t, each consumer i born in period t for whom $v_i>v_L^{C}$ and who does not own a used unit at the beginning of the period purchases a new unit from firm j_{it} and m^N units of maintenance from a competitive maintenance seller.

v) In each period t′, t′>t, each consumer i born in period t for whom $v_i>v_L^{C}$ and who does own a used unit at the beginning of the period purchases a new unit from firm j_{it} and m^N units of maintenance from a competitive maintenance seller if $m_{it}^{U}>m^C$, and purchases m_{it}^{U} units of maintenance from a competitive maintenance seller if $m_{it}^{U}\leq m^C$.

vi) $EU_i^{C}<(=)EU_i^{*}$ for all i for whom $v_i>(\leq)v_L^{*}$.

Proposition 1 tells us that, when the maintenance market is competitive and firms cannot commit in the first period to future prices for new units, inefficiencies arise. The first inefficiency is that maintenance decisions are different than the first-best or commitment maintenance decisions. The logic here is as follows. Think back to the commitment case. In that case each durable-goods producer commits in the first period to new-unit prices in every period t, $t\geq 1$, equal to c. The result was that consumers made efficient choices each period concerning when to maintain rather than replace used units.

Now consider what happens in the absence of commitment. In particular, consider a firm that sells new units for the first time in period t and its pricing decision in subsequent periods. As in the commitment case, the firm could choose to price new units in all subsequent periods at c and, if it chose this behavior, then the firm's consumers would make efficient maintenance choices. However, this behavior translates into present discounted value of profits for the firm in periods t+1 and later equal to zero. But clearly, since the switching cost means the firm has market power in selling new units after period t to consumers who purchased new units from the firm in period t, the firm can earn a strictly positive present discounted value of expected profits in periods t+1 and later by setting new-unit prices above c. The result is that the firm chooses new-unit prices in periods t+1 and later above c and consumers no longer make efficient choices concerning whether to maintain or replace their used units.

Rather, because new-unit prices are above the firm's marginal cost of production while maintenance is priced competitively, consumers maintain their used units more often than is efficient and there is a corresponding reduction in both consumer and social welfare.

The second inefficiency is that fewer individuals consume the durable product (and maintenance) than in the first-best or commitment case. This result is a consequence of the first inefficiency described above. In both the commitment and no-commitment cases, individuals consume the durable product as long as the net benefit of doing so is greater than or equal to zero. Holding v_i fixed, the inefficient maintenance decisions in the no-commitment case lower the net benefit of consuming the durable product. The result is that some individuals who receive positive net benefits from consuming the durable product in the commitment case would receive strictly negative net benefits from consuming the product in the no-commitment case. Hence, in the first-best or commitment case these individuals purchase the product while they do not in the no-commitment case.[16]

The third inefficiency is that, similar to a result found in Farrell and Shapiro (1988), each new cohort of consumers when first entering the market purchases new durable units from a set of durable-goods producers who start production in that period. This is inefficient because learning-by-doing means the first-best efficient outcome minimizes the number of new units produced by firms that are in their first period of operation. The reason that in Proposition 1 each cohort of consumers purchases from a different set of durable-goods producers is the limited ability that firms have to price discriminate in the setting considered in Proposition 1.[17]

To see this, consider the cohort of consumers born in period t, $t>1$. For firms that have not sold new units prior to period t, competition and the fact that selling to such a consumer in period t will yield positive profits in later periods means that such firms will be willing to sell new units in period t to consumers in this cohort at a price strictly less than c. Further, because of competition, the present

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[16] Note that, although the set of individuals who purchase the durable product in the no-commitment case is not first-best efficient, it is second-best efficient. That is, if we take as fixed the inefficient maintenance decisions, then the set of individuals who choose to purchase and consume the durable product is the socially optimal set.

[17] Farrell and Shapiro consider a duopoly model characterized by switching costs and consumers who enter the market in every period. In their analysis one firm sells new units to new consumers in even periods while the other sells new units to new consumers in odd periods. The similarity is that, in both analyses, each new cohort of consumers when entering the market purchases new durable units from durable-goods producers who are not trying to sell replacement units in that period to older consumers, where this occurs because of the limited ability for firms to price discriminate.

discounted value of expected profits from period t forward associated with such sales equals exactly zero. Now consider a firm that sold new units prior to period t. From above, we know that selling to a consumer born in period t requires a period-t price below c and the sale would yield a present discounted value of expected profits from period t forward equal to zero. The result is that, since switching costs mean the firm can earn positive profits by having the period-t price for a consumer who does not trade-in a used unit be above c, the firm maximizes profits by not selling to consumers born in period t.

The next step of the analysis is to consider actions that a firm might take in order to avoid the inefficiencies identified above. In particular, we explore the extent to which a competitive durable-goods producer can avoid these inefficiencies by monopolizing the maintenance market for its own product. Below EU_i^M denotes the present discounted value evaluated in the period the consumer is born of the expected net benefits received by consumer i in this case. Also, p_{jt}^N denotes the price that durable-goods producer j charges in period t for m^N units of maintenance to individuals who purchase new units of output from the firm in period t, while $p_{jt}^U(m)$ denotes the price that durable-goods producer j charges in period t for m units of maintenance to individuals who own used units of the firm's product at the beginning of period t.

Proposition 2: Suppose each firm cannot commit in the first period to the prices it will charge in subsequent periods for a new unit of output, but each firm has the option of monopolizing the maintenance market for its own product at the beginning of each period. Then every equilibrium is characterized by i) through vi), where in each equilibrium every durable-goods producer monopolizes the maintenance market for its own product and includes a no-trade clause in its sales of maintenance in every period t, $t \geq 1$.[18]

i) For every firm j and period t, if firm j sold new units in the first period then $P_{jt1}^M + p_{jt}^N = P^+ < c + m^N$ and $P_{jt2}^M + p_{jt}^N = P_{jt3}^M + p_{jt}^N = P^+ + \Delta$. Also, no firm starts production after the first perod.

ii) For every firm j and period t, if firm j sold new units in the first period then $p_{jt}^U(m) = P^+ + \Delta$ for all $m < m^*$, $p_{jt}^U(m) > P^+ + \Delta$ for all $m > m^*$, and $p_{jt}^U(m) \geq P^+ + \Delta$ for $m = m^*$.

iii) Each consumer i born in period t for whom $v_i > v_L^*$ ($v_i \leq v_L^*$) purchases a new unit and m^N units

[18] There are multiple equilibria of the type described for a variety of reasons including that $p_{jt}^U(m)$ is not uniquely defined and when a firm sells a new unit and m^N units of maintenance the sum of the prices is uniquely defined but the individual prices are not.

of maintenance in period t from the same durable-goods producer (never purchases new units, used units, or maintenance).

iv) In each period t′, t′>t, each consumer i born in period t for whom $v_i > v_L^*$ and who does not own a used unit at the beginning of the period purchases a new unit and m^N units of maintenance from firm j_{it}.

v) In each period t′, t′>t, each consumer i born in period t who does own a used unit at the beginning of the period purchases a new unit and m^N units of maintenance from firm j_{it} if $m_{it}^U > m^*$, purchases m_{it}^U units of maintenance from firm j_{it} if $m_{it}^U < m^*$, and chooses one of these two behaviors if $m_{it}^U = m^*$.

vi) $EU_i^M = EU_i^*$ for all i.

Proposition 2 demonstrates that a durable-goods producer can avoid the inefficiencies identified above by monopolizing the maintenance market for its own product. The logic here is as follows. As just discussed, because the prices for replacement units are above marginal cost when the maintenance market is competitive and commitment is not possible, consumers in that case make inefficient maintenance decisions and this also causes fewer individuals to consume the durable product than in the commitment case. Now consider a durable-goods producer that monopolizes the maintenance market for its own product in every period. By optimally setting the prices for replacement units and the price schedules for maintenance, in every period the firm is able to extract all the surplus from consumers who purchased new units from the firm in previous periods (call them the firm's "repeat customers"). In turn, since the firm is able to extract all the surplus, the firm has an incentive to induce its repeat customers to make efficient maintenance decisions. The result is that consumers make efficient maintenance choices and this, in turn, also causes the same set of individuals to consume the durable product as in the commitment case.

To be more specific, the firm extracts all the surplus from repeat customers by charging $P^+ + \Delta$ for replacement units with m^N units of maintenance and the same price $P^+ + \Delta$ for used-unit maintenance levels less than m*, where new units with m^N units of maintenance are available at the same time from other firms at the price P^+. The firm then induces efficient maintenance versus replacement decisions by charging more than $P^+ + \Delta$ for used-unit maintenance levels above m*, which causes repeat customers with required maintenance levels above m* to replace rather than maintain their used units. Notice that there is

surplus to be captured by the firm both because of the switching cost and because some used units require less than m* units of maintenance.[19]

Now let us discuss the role of the no-trade clauses in the equilibrium maintenance contracts. As stated earlier, the no-trade clause allows a firm to price discriminate between new customers and repeat customers. That is, in the absence of such clauses, the possibility of resale limits a firm's ability to lower the price a firm offers a new consumer (since such a consumer could resell the new unit and maintenance to the firm's repeat customers to whom the firm would like to charge higher prices). In turn, this improved ability to price discriminate is what allows for the elimination of the third inefficiency associated with Proposition 1. As discussed above, given learning-by-doing, efficiency requires minimizing the number of new units produced by firms that are in their first period of operation. The improved ability to price discriminate associated with no-trade clauses minimizes this number by having no firm start production after the first period.

It is also of interest that evidence in the Kodak case is consistent with the type of price discrimination between new customers and repeat customers found in Proposition 2. In particular, in the majority opinion in the 1992 U.S. Supreme Court case, Judge Blackmun argues that the evidence presented by Kodak is consistent with Kodak price discriminating by charging low prices to new customers and high prices to repeat customers who face high switching costs.

Finally, suppose the model did not incorporate learning-by-doing, i.e., each durable-goods producer had a constant marginal cost of c independent of whether it had strictly positive production in the previous period. Then, in addition to the equilibria described in Proposition 2, there would be another set of equilibria in which durable-goods producers do not include no-trade clauses in their maintenance contracts. Besides the non-inclusion of the no-trade clauses, the only other difference between these equilibria and the ones described in Proposition 2 is that each cohort of consumers purchases from durable-goods producers who start their operations in the period that the consumers are born. The logic for this last result is the same as that given for the similar result found in Proposition 1. Because of the possibility of resale on the secondhand market, without the no-trade clause a durable-goods producer

[19] In equilibrium, consumers who own used units with required maintenance levels less than m* are indifferent between maintaining and replacing their used units. One could think of the firm charging $P^{+}+\Delta-\varepsilon$ for maintenance levels below m* to ensure that these consumers maintain rather than replace their used units. However, since the smallest strictly positive value for ε is not defined, any Nash equilibrium will be such that the firm charges $P^{+}+\Delta$ for used-unit maintenance levels below m* and consumers with used units with required maintenance levels below m* choose to maintain them.

cannot offer a lower new-unit price to a newly-born consumer than to a consumer who purchased from the firm in the past. In turn, because switching costs mean firms would like to price discriminate between these groups, the end result is that in the absence of no-trade clauses each cohort of consumers purchases from a different set of durable-goods producers. As indicated, the presence of learning-by-doing eliminates these equilibria because with learning-by-doing it is not efficient to have each new cohort of consumers purchase from a new set of durable-goods producers.

III. EXTENSIONS

In this section we discuss two extensions of the model analyzed in the previous section. The first addresses why a firm would monopolize the maintenance market for its own product rather than sign a long-term contract that specifies future prices for replacement units. The second explains why a firm would monopolize the maintenance market for its own product by refusing to sell spare parts to alternative maintenance suppliers rather than simply raise the price for spare parts.

A) Why Not Long-Term Contracts?

In the analysis of Section II a durable-goods producer could ensure efficiency in either of two ways. It could ensure efficiency by either monopolizing the maintenance market for its own product or signing long-term contracts with consumers that specify future prices for new units. But this raises the question, since a long-term contract of this sort would not be difficult to write, why would a firm monopolize the maintenance market for its own product rather than sign such a long-term contract? In this subsection we discuss a variant of the model considered in Section II that addresses this question.

In this extension everything is the same as in the model of Section II except that a firm makes a once and for all choice of durability at the beginning of the first period prior to other decisions, where an increase in the durability built into new units both increases the marginal cost of production and reduces the expected level of maintenance required by units when they become used (similar results would be found by assuming that each firm makes a durability choice for each period at the beginning of the period). To be specific, each firm j chooses a durability level in its first period of operation, denoted d_j. Firm j's marginal cost in this first period is then $c'+s(d_j)$ while in later periods it is $c+s(d_j)$, where $c'>c>0$,

$s(0)=0$, $s(\infty)=\infty$, $s'(0)=0$, and $s'(d)>0$ and $s''(d)>0$ for all $d>0$.[20] Further, the level of maintenance required by a used durable unit produced by any firm j is given by $q^U/(1+d_j)$. In this specification q^U is the realization of a random draw from the probability density function k(.), where $k(q^U)>0$ for all $q^U \in (0,\infty)$.

In addition to the information assumptions made in Section II, we now also assume that a firm's durability choice is neither publicly observable nor verifiable. We believe this is a natural assumption given durability controls the speed of product deterioration which in the real world is frequently difficult to judge by observing products when they are new. By assuming durability choice is neither publicly observable nor verifiable, we introduce the possibility of a standard moral-hazard problem in which firms underinvest in durability because each period's new-unit prices do not directly reflect durability choice. Finally, our focus is again on the nature of equilibrium in the limit as c' approaches c from above.

In Proposition 3 we analyze the above model under the assumption that a durable-goods producer can either sign long-term contracts that specify future prices for replacement units or monopolize the maintenance market. Below d* denotes the first-best durability choice.

Proposition 3: Suppose each firm can either commit in the first period to the prices it will charge in subsequent periods for a new unit of output or the firm can monopolize the maintenance market for its own product at the beginning of each period. Then, substituting $c+s(d^*)$ for c in i) of Proposition 2, every equilibrium is characterized by i) through vi) of Proposition 2, where in each equilibrium every durable-goods producer chooses durability level d*, monopolizes the maintenance market for its own product, and includes a no-trade clause in its sales of maintenance in every period t, $t \geq 1$.

Proposition 3 tells us that in this model, even though both long-term contracts and monopolizing the maintenance market are available for avoiding the maintenance versus replacement inefficiency, the only equilibria are ones in which firms choose to monopolize the maintenance markets for their own products. To understand this result, first consider why long-term contracts that specify future prices for replacement units result in a first-best outcome in the model of Section II. In that analysis the main behavior that needs to be controlled to achieve a first-best outcome is each consumer's choices concerning when to maintain and when to replace used units. In turn, a firm can provide its consumers

[20] We also assume that s(.) is sufficiently convex that the first-best-durability choice is uniquely defined.

with an incentive to make efficient maintenance decisions by committing to future prices for replacement units equal to the marginal cost of production.

Now consider what happens given the model considered here when a firm signs a long-term contract that specifies future prices for replacement units. As before, efficiency requires each consumer to make efficient decisions concerning whether to maintain or replace used units. But now efficiency also requires each firm to make an efficient choice concerning the durability of its output. The problem is that a firm that simply commits to future prices for replacement units cannot induce both behaviors to be chosen efficiently. To see this, suppose a firm that sells new units in the first period charges a price and commits to future prices for replacement units equal to the marginal cost of production that corresponds to the first-best level of durability (given an efficient durability choice, these are the prices needed for the replacement versus maintenance decisions to be efficient and for the firm to earn zero expected profits). Given this commitment, the firm would not have an incentive to make the efficient durability choice. The reason is that, if it makes the efficient durability choice, then as indicated the firm's present discounted value of profits equals exactly zero. But, given that the durability choice is unobservable, the firm could increase this present discounted value by lowering the durability level below the efficient amount.

The final step of the argument is to consider what happens when a firm chooses to monopolize the maintenance market for its own product in each period rather than commit to future prices for replacement units. The result is that the firm makes the efficient durability choice and consumers make efficient choices concerning maintenance, where the logic for this result is the same as the logic for why monopolizing the maintenance market resulted in first-best behavior in Section II. By monopolizing the maintenance market in any pair of periods t-1 and t a firm is able to extract all the surplus from individuals who consumed a unit of the firm's product in period t-1. In turn, since the firm is able to extract all the surplus, the firm has an incentive for decisions to be efficient. The result is that consumers make efficient maintenance choices and the firm chooses the efficient durability level.

B) Why Not Increase the Price for Spare Parts?

One interesting aspect of the allegations against Kodak and the other firms that have monopolized the maintenance markets for their own products concerns the manner with which that monopolization is typically achieved. As mentioned in the Introduction, a typical allegation is that the durable-goods producer monopolizes the maintenance market for its own product by refusing to sell spare

parts to alternative maintenance suppliers. But as pointed out earlier by Chen, Ross, and Stanbury (1998), this raises the question, why doesn't the firm simply increase the price for spare parts rather than refuse to sell spare parts and monopolize the maintenance market? Here we discuss a variant of the model considered in Section II that addresses this question.

In this extension everything is the same as in the model of Section II except that maintenance consists of both service and replacement parts. A new unit of output requires one unit of service and a fixed number of replacement parts that we denote r^N, $r^N \geq 0$, while a used unit requires one unit of service and a stochastic number of parts, denoted r^U. The value for r^U for any specific used unit is the realization of a random draw from the probability density function h(.), where $h(r^U)>0$ for all $r^U \in (0,\infty)$. Similar to the model of Section II, we assume that a consumer who owns a used unit at the beginning of a period observes the number of replacement parts that will be required by his or her used durable unit.[21] Further, replacement parts for a durable unit produced by firm j can only be manufactured by firm j itself. Hence, firm j's products can be maintained by alternative maintenance suppliers only if these suppliers are able to purchase replacement parts from firm j. There are no fixed costs for producing either parts or service, while the monopolist's constant marginal cost for producing parts is c_r, $c_r>0$, and every firm has a constant marginal cost of providing service equal to c_s, $c_s>0$. Finally, we assume $V>c+c_s+r^N c_r$ which is analogous to the assumption in Section II that $V>c+m^N$ (and we again consider the nature of equilibrium in the limit as c′ approaches c from above).

In Proposition 4 we analyze this model under the assumption that each durable-goods producer must choose to either allow competition in the maintenance market by selling replacement parts to alternative maintenance suppliers or monopolize the maintenance market by refusing to sell spare parts to alternative maintenance suppliers.[22]

Proposition 4: Suppose each firm cannot commit in the first period to the prices it will charge in subsequent periods for a new unit of output, but each firm has the option of monopolizing the maintenance market for its own product at the beginning of each period by refusing to sell spare parts to

[21] Although we have not shown this formally, we believe the conclusions also follow if each consumer does not observe the exact number of replacement parts that will be required by his or her used unit, but only observes a signal indicating the expected number of parts that will be required.

[22] Equivalently, a durable-goods producer could monopolize the maintenance market by offering to sell spare parts but setting a prohibitively high price on the parts.

alternative maintenance suppliers. Then in every equilibrium every durable-goods producer monopolizes the maintenance market for its own product and includes a no-trade clause in its sales of maintenance in every period t, $t \geq 1$.[23]

Proposition 4 tells us that, if each durable-goods producer cannot commit to future prices for new units, then as in Section II in every period each firm monopolizes the maintenance market for its own product. There is a difference, however, in that now each firm chooses this behavior rather than allow competition in the maintenance market by selling replacement parts and simply increase the replacement-part price.[24] The logic for this result is as follows. Let r* be such that it is efficient for used units to be maintained when $r^U < r^*$ and for used units to be replaced when $r^U > r^*$, and consider consumers who own used units of firm j's output at the beginning of a period. Similar to what we found in Proposition 2, in this extension each firm j extracts all the surplus from consumers whose used units require $r^U < r^*$ replacement parts by charging them a price for maintenance equal to $P^+ + \Delta$.[25] That is, extracting all the surplus from these consumers requires that the price charged to each such consumer for maintenance be independent of the amount of maintenance required by the consumer's used unit or, more precisely, independent of the number of replacement parts required.

Given this, suppose a firm does not monopolize the maintenance market but rather simply increases the price for replacement parts. Let P_{Rt} be the price the durable-goods producer charges for a replacement part in period t and r_{it} denote the number of replacement parts required by the used unit owned by individual i at the beginning of period t. Because the maintenance market is competitive, in equilibrium the price charged in any period t for maintenance that consists of one unit of service and r_{it} replacement parts will be $c_S + r_{it}P_{Rt}$. That is, the price of maintenance will be increasing in the number of replacement parts required. But since extracting all the surplus from consumers who choose to maintain

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[23] Also, results similar to i) through vi) of Proposition 2 hold, where the differences are that the maintenance price function, maintenance costs, and the critical maintenance level defining the maintenance versus replacement decision are all defined in terms of the number of spare parts required rather than the level of maintenance required.

[24] If we combined the first and second extensions then, whether or not a firm could commit to future prices for new units, each durable-goods producer would monopolize the maintenance market for its own product rather than allow competition in that market and simply increase the price for replacement parts.

[25] On the other hand, each firm j induces other consumers whose used units require $r^U > r^*$ replacement parts to purchase firm j's new units at $P^+ + \Delta$ by charging them a price for maintenance higher than $P^+ + \Delta$ (consumers for whom $r^U = r^*$ can either purchase maintenance or buy a new unit in equilibrium).

their used units requires that these consumers pay a price for maintenance, $P^{+}+\Delta$, that is independent of the number of replacement parts required, we now have that by simply increasing the price of replacement parts the firm is unable to extract all the surplus in period t from these consumers. Hence, since monopolizing the maintenance market allows a firm to extract all the surplus from these consumers while simply increasing the price of replacement parts does not, the firm will choose to monopolize the maintenance market.

IV. DISCUSSION

In this section we first discuss the major alternative explanations that have been put forth for why a durable-goods producer would monopolize the maintenance market for its own product, and then discuss the antitrust implications of our analysis.

A) Alternative Theories

We begin by discussing three closely related theories in which the firm monopolizes the maintenance market in order to exploit market power after consumers are locked-in. The literature does not always make a clear distinction between the terms consumer lock-in and consumer switching costs. In the discussion that follows we do make a clear distinction between these terms. We use the term consumer lock-in to refer to a setting in which a consumer who has purchased a durable good needs to also purchase maintenance to consume the good. We use the term consumer switching costs to refer to a setting in which a consumer faces a cost of switching between producers at the date that the consumer replaces a used unit with a new unit. The first three theories discussed below require consumer lock-in but not consumer switching costs, i.e., a durable unit requires maintenance but a consumer is indifferent between different firms' products at the time that replacement occurs. In contrast, our analysis incorporates both consumer lock-in and consumer switching costs, i.e., a durable unit requires maintenance and at the replacement date a consumer prefers a new unit produced by the same firm that manufactured the unit the individual consumed in the previous period.

A key element in these three theories is that consumers are locked-in once they purchase a new unit of output from a durable-goods producer. The producer exploits the consumers' locked-in positions by first stopping other firms from selling maintenance and then raising the price of maintenance, which results in a standard deadweight loss. The deadweight loss has two components. Consumers of used

units purchase less than the socially optimal amount of maintenance and consumers replace their used units too quickly. In the "surprise" theory, consumers expect that the maintenance market will remain competitive. The result is that consumers are hurt by the maintenance-market monopoly both because of the equivalent of a lump sum transfer between the consumers and the firm caused by the surprise and the standard deadweight loss mentioned above. In contrast, in the closely related "costly-information" theory consumers simply ignore the cost of maintenance in their original decisions to purchase new units. In this theory there is no transfer between the consumers and the firms because competitive firms will reduce the price for new units so that they receive zero profits in equilibrium.[26] However, similar to the surprise theory, the monopoly pricing of maintenance results in a standard deadweight loss.[27]

The third theory that depends on the exploitation of locked-in consumers is the "lack-of-commitment" theory developed in Borenstein et al. (1995). In contrast to the two theories described above, in this explanation consumers correctly anticipate whether a durable-goods producer will monopolize the maintenance market and are willing to pay less for a new unit when they anticipate monopolization. In such circumstances a durable-goods producer would want to commit to allowing competition in the maintenance market, but monopolization occurs because of a lack of ability to commit. In this theory, as in the costly-information theory, the only cost of the practice is the deadweight loss due to the monopoly pricing of maintenance. Note, both Shapiro (1995) and Chen and Ross (1998) provide formal analyses that suggest this deadweight loss is likely to be small.

One can question the applicability of each of the above theories to the cases in which monopolizing the maintenance market has been observed. For example, the costly-information theory assumes uninformed consumers which seems unlikely in many of the cases in which the cost of maintenance was a significant proportion of the total cost of using the product. Similarly, the lack-of-commitment theory assumes commitment is not possible but this also seems to be of questionable applicability because long-term maintenance contracts are quite common in many of the industries in which the practice has been observed. Further, another criticism applies equally to all three theories. As

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[26] The discussions we have seen of the surprise theory do not make clear why in that theory competition in the market for new units does not eliminate the transfer between consumers and firms.

[27] One other difference between the theories is that in the surprise theory a durable-goods producer that monopolizes the maintenance market is hurt in the market for new units because it establishes a reputation for exploiting locked-in consumers. This is not true in the costly-information theory.

discussed earlier, in the typical case the durable-goods producer monopolizes the maintenance market by refusing to sell spare parts to alternative maintenance suppliers. The problem is that, at least in the original formulations, none of the three theories explains this behavior. In each theory the durable-goods producer could have achieved its goal by simply raising the price of spare parts rather than monopolizing the maintenance market by refusing to sell spare parts to alternative maintenance suppliers.[28]

Another explanation for maintenance-market monopoly is that the practice helps a firm more effectively price discriminate (this explanation is developed in Chen and Ross (1993) and Klein (1993)). This is the standard metered-sales explanation for tie-ins used, for example, to explain IBM's practice of requiring purchasers of its tabulating machines to also purchase cards from IBM. That is, in this theory consumers with higher valuations for the durable-goods-producer's product are also heavier users of maintenance, with the result that the seller can more effectively price discriminate by monopolizing the maintenance market and raising its price. This theory provides a rationale for why a firm with market power would monopolize the maintenance market for its own product, but does not explain why a firm with little or no market power would monopolize the maintenance market for its own product.[29]

More recently, similar to our paper some authors have put forth efficiency rationales for maintenance-market monopolization, although different than our approach these authors have not focused on the role of switching costs. For example, Chen and Ross (1999) consider a competitive setting in which consumers vary in their intensity of usage and each durable-goods producer bundles free maintenance for a limited time with the sale of a new durable unit. They show that monopolizing the maintenance market after the free maintenance expires is needed to stop the subsidization of high-

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[28] As argued earlier in Chen and Ross (1993,1998) and Klein (1993), one way of extending each of these theories so that monopolizing the maintenance market is preferred to simply raising the price of spare parts is by assuming that service and the replacement of defective parts are substitutes in the maintenance production function. Given this assumption, if the durable-goods producer simply raised the price of spare parts, the alternative maintenance suppliers would respond by inefficiently substituting service for spare parts. Hence, monopolizing the maintenance market would be more profitable because it would avoid this inefficient substitution of service for spare parts. It is interesting to note that, in contrast to the public-policy recommendation that follows from the simple version of each of the theories, this extension suggests that the government should allow durable-goods producers to monopolize the maintenance markets for their own products unless the government also regulates the price of spare parts. The reason is that, if the government does not regulate the price of spare parts, there will be a monopoly price for maintenance whether or not the government allows monopolization of the maintenance market and thus allowing monopolization is superior from a social-welfare standpoint because it avoids the inefficient substitution of service for spare parts.

[29] Klein argues that in the real world there is significant price discrimination even by firms with little market power, and thus that the price-discrimination argument should not be ruled out as a possible explanation for why such a firm would monopolize the maintenance market for its own product.

intensity users by low-intensity users, and the practice also increases social welfare due to more efficient maintenance decisions. Another example is Elzinga and Mills (2001) who consider a durable-goods-oligopoly model characterized by fixed costs and constant marginal costs for the production of durable units and maintenance. They show that Ramsey-optimal pricing requires above marginal cost pricing for both new durable units and maintenance and this can only be achieved when a durable-goods producer monopolizes the maintenance market for its own product.[30]

In summary, there are a number of alternative explanations for why a durable-goods producer would monopolize the maintenance market for its own product. However, we believe that the explanation put forth in Sections II and III is a better match than any of the alternatives for the evidence in the *Kodak* case and other cases in which a firm with little or no market power monopolized the maintenance market for its own products. For example, our theory explains why a durable-goods producer would monopolize the maintenance market even if consumers are well informed and long-term contracts are feasible. In contrast, the costly-information theory and lack-of-commitment theories do not explain why a firm would monopolize the maintenance market in such a case. Our theory is also consistent with a firm monopolizing the maintenance market when it has little or no market power, while the price discrimination theory fits more easily with firms characterized by significant market power. Finally, as discussed further in the next subsection, our theory is the only one that incorporates consumer switching costs in an essential way and the evidence indicates that this was an important aspect of a number of the cases (see the Introduction for a discussion).

B) Antitrust Implications

Since the *Kodak* decision, significant attention has been paid to whether or not a durable-goods producer should be allowed to monopolize the maintenance market for its own products by refusing to sell spare parts to alternative maintenance suppliers. Based on previous theoretical explanations for this behavior discussed in Subsection IV.A, a number of authors have argued that prohibiting such behavior serves to enhance social welfare in certain settings (see, e.g., Salop (2000)). We now discuss the

[30] Another argument is the reputation argument put forth in Shapiro (1995). Shapiro argues that, if a firm's incentive to maintain a positive reputation due to effects on long-run profitability is sufficiently strong, then a durable-goods producer that monopolizes the maintenance market for its own product will charge a competitive rather than a monopoly price for maintenance. Note that this argument does not, in fact, provide an explanation for maintenance-market monopolization in that in this argument the firm's profitability from monopolizing the maintenance market is no higher than if it allowed the maintenance to be provided by competitive sellers.

implications of our analysis for whether the Courts should allow a durable-goods producer to monopolize the maintenance market for its own products.

We begin by reviewing what happens in our model when monopolizing the maintenance market is and is not allowed. Suppose that firms cannot commit in the first period to future prices for new units and the maintenance market is competitive. We showed that in this case, due to switching costs, firms charge high prices for replacement units which, in turn, reduces both social welfare and consumer welfare. This reduction occurs mainly because consumers respond to the high prices for replacement units by sometimes maintaining used units when it would be efficient to replace those units. Now suppose that each firm has the option of monopolizing the maintenance market for its own product. The result is that each firm monopolizes the maintenance market for its own product and, because this avoids the inefficiency concerning consumer maintenance decisions, there is a corresponding increase in both social welfare and consumer welfare.

What do these results imply for the question considered by the U.S. Supreme Court in the *Kodak* case, i.e., should a durable-goods producer with little or no market power in the market for new units be allowed to monopolize the maintenance markets for its own products? The Court's ruling was that, even if Kodak had no market power in the market for new units, it could still be guilty of having illegally monopolized the maintenance markets for its own products by refusing to sell spare parts to alternative maintenance suppliers. This ruling is consistent with the arguments of Borenstein et al. and others discussed previously. They argue that when Kodak monopolized the maintenance market social welfare fell because a monopoly price for maintenance results in a standard deadweight loss, where this loss consists of two components. One component is that consumers purchase less than the socially optimal amount of maintenance, while the other is that consumers replace their used units too quickly.

An important contribution of our analysis is to show that in the presence of consumer switching costs the social-welfare implications of how monopolizing the maintenance market affects replacement decisions are quite different than in the analyses of Borenstein et al. and others. In particular, our analysis shows that, if in a setting characterized by competitive durable-goods producers there are consumer switching costs, then a competitive price for maintenance will result in consumers replacing used units inefficiently often while monopoly maintenance results in efficient decisions on this dimension. Recall that the presence of consumer switching costs was an important aspect of the *Kodak* case (see the discussion in the Introduction). Hence, we would argue that the U.S. Supreme Court made an incorrect

ruling in that case. If a firm is judged to lack significant market power and there is also significant consumer switching costs, then the firm should be allowed to monopolize the maintenance market for its own product since in that type of setting the result of monopolization is improved efficiency concerning the replacement versus maintenance decision.

On the other hand, in the absence of consumer switching costs the argument for not allowing maintenance-market monopolization is stronger. In the absence of switching costs, the arguments of Borenstein et al. and others suggest that maintenance-market monopolization may reduce social welfare because consumers purchase too little maintenance and replace their machines too often. Hence, in such a setting not allowing maintenance-market monopolization may increase both social welfare and consumer welfare. There are two complications associated with this argument, however.

First, suppose there are no consumer switching costs and a durable-goods producer wants to monopolize the maintenance markets for its own products for reasons consistent with the arguments of Borenstein et al. and others. Further, suppose the firm achieves monopolization by refusing to sell spare parts to alternative maintenance suppliers. Then eliminating the inefficiency might require not only for the firm to sell spare parts to the alternative suppliers but also for the government to regulate the price of spare parts (otherwise, the firm could achieve most or all of what it wants by simply raising the price of spare parts – see footnote 28 for a related discussion). But this is problematic because it is not at all clear that regulating the price of spare parts is a feasible intervention for the antitrust authorities. Second, in general it is difficult for courts to judge motivation and, given theory tells us that competitive firms typically behave in ways that maximize social welfare, the courts should be worried about type two errors, i.e., the courts prohibiting the practice when the practice in fact raises social welfare. We thus feel that the evidence concerning motivation should be quite strong before the courts intervene.

V. CONCLUSION

In this paper we demonstrated two important results. Consider a setting characterized by consumer switching costs and an inability on the part of durable-goods producers to commit to future prices for replacement units. Our first finding is that, if both the market for new durable units and the maintenance market are competitive, then inefficiencies result that lower both social welfare and consumer welfare. The logic is that, in order to achieve efficient maintenance decisions on the part of consumers, a firm would like to commit to prices for replacement units equal to the marginal cost of

production. However, in the absence of the ability to commit, the presence of consumer switching costs causes firms to charge prices for replacement units above marginal cost. The result is inefficient maintenance decisions, fewer consumers purchasing the durable product than in the first-best or commitment case, and a corresponding reduction in both consumer welfare and social welfare.

Our second important finding is that monopolizing the maintenance market for its own product is a way for a competitive durable-goods producer to avoid the inefficiencies described above. By monopolizing the maintenance market a firm is able to extract all the surplus at the date consumers are choosing whether to maintain or replace used units. The result is that, because it is capturing all the surplus, the firm has an incentive to price in such a way that consumers make efficient choices concerning whether to maintain or replace used units and this, in turn, results in the first-best efficient number of consumers purchasing the durable product. Further, since in a competitive market it is the consumers who capture any increase in social welfare, we now have that when a durable-goods producer monopolizes the maintenance market for its own product the result is an increase in both consumer and social welfare.

There are a number of directions in which the analysis in this paper could be extended. However, the one that we feel is the most interesting is extending our result concerning the importance of commitment in competitive durable-goods markets. As we briefly discussed in the Introduction, earlier literature on commitment in durable-goods markets builds on the initial insight of Coase (1972) and Bulow (1982) and focuses on monopoly models. In Sections II and III we showed that whether or not a firm has the ability to commit can also be important in a competitive durable-goods setting when there are consumer switching costs. The finding is interesting because it suggests that the issue of commitment and time inconsistency may be important in many more durable-goods markets than previously realized. In future work we plan to extend our analysis both by investigating whether there are alternative avenues through which the ability to commit becomes important in competitive settings, and whether there are practices other than monopolizing the maintenance market that competitive firms may employ in order to avoid problems due to an inability to commit.

APPENDIX

We first define some notation. Let ξ be a function whose arguments are m and v_i. Throughout the proofs $E(\xi)$ will denote the unconditional expected value of ξ, while $E_i(\xi)$ denotes the expected value conditional on v_i. Also, let V_i be the value of consumer i at the beginning of a period in which the

consumer does not own a used unit but consumed a used unit in the previous period, while $V_i^U(m)$ is the value of consumer i at the beginning of a period in which the consumer owns a used unit with maintenance realization m.

Proof of Proposition 1: We first show that there exists an equilibrium that satisfies $v_L^* < v_L^C < V$, $m^C > m^*$, and i) through vi). We then argue that no equilibrium exists that does not satisfy these conditions. Note, since we consider the nature of equilibrium in the limit as c′ approaches c from above, we let c′ be arbitrarily close to c.

We start by supposing that in any period t every firm that has not sold new units in the past offers a new unit at a price P′, $c-\Delta<P'<c$, where P′ satisfies a zero-profit condition, and that there is never trade on the secondhand market. Because of the switching cost, we know that a firm for whom there are consumers who consumed a unit of the firm's product in the previous period can earn positive profits by setting $P_{jt1}^C \geq P_{jt2}^C > P'$ and selling a positive number of units. Given that P′ satisfies a zero-profit condition, we thus have that $P_{jt1}^C \geq P_{jt2}^C > P'$ for such a firm.

Given this, consider first a consumer who does not own a used unit at the beginning of period t and did not consume a unit in the previous period. This consumer can either purchase nothing or purchase a new unit and m^N units of maintenance. Given $P_{jt1}^C > P'$, if the consumer chooses the latter option he or she is best off purchasing from a firm that has not sold new units in the past. Hence, EU_i^C is given by (A1).

(A1) $$EU_i^C = \max\{0+\beta EU_i^C, v_i - P' - m^N + \beta E_i(V_i^U(m))\}$$

(A1) tells us that consumer i never purchases a new unit if $v_i - P' - m^N + \beta E_i(V_i^U(m)) \leq 0$.

Now consider a consumer who does not own a used unit at the beginning of period t but consumed a unit in the previous period produced by firm j. This consumer can either purchase nothing, purchase a new unit from firm j at the price P_{jt1}^C and m^N units of maintenance, or purchase a new unit from a different manufacturer and m^N units of maintenance (as earlier, the best option in this case is to purchase a new unit at a price P′ from a firm that has not sold new units in the past). Hence, V_i is given by (A2).

(A2) $$V_i = \max\{0+\beta EU_i^C, v_i + \Delta - P_{jt1}^C - m^N + \beta E_i(V_i^U(m)), v_i - P' - m^N + \beta E_i(V_i^U(m))\}$$

Similarly, consider a consumer who owns a used unit at the beginning of period t that was produced by firm j and has maintenance requirement m. This consumer either purchases nothing, purchases m units of maintenance, purchases a new unit from firm j at either P_{jt1}^C or P_{jt2}^C, or purchases a new unit from a different manufacturer . Hence, $V_i^U(m)$ must satisfy (A3).

(A3) $$V_i^U(m) = \max\{0+\beta EU_i^C, v_i + \Delta - m + \beta V_i, v_i + \Delta - \min(P_{jt1}^C, P_{jt2}^C) - m^N + \beta E_i(V_i^U(m)), v_i - P' - m^N + \beta E_i(V_i^U(m))\}$$

Consider a firm that is choosing P_{jt1}^C and there are consumers in period t who consumed a unit of the firm's product in the previous period but do not own a used unit at the beginning of period t. Given we know from above that each such consumer must satisfy $v_i - P' - m^N + \beta E_i^U(V_i^U(m)) > 0$ and that the firm

cannot earn positive profits by selling to consumers who did not consume a unit of the firm's product in the previous period, (A2) and (A3) immediately tell us that the optimal choice must satisfy $P_{jt1}^{C} \leq P' + \Delta$. Further, since for any $P_{jt1}^{C} < P' + \Delta$ the firm could increase profits by raising the price slightly, we have $P_{jt1}^{C} = P' + \Delta$. Hence, (A2) reduces to (A4) for each such consumer.

(A4) $$V_i = v_i - P' - m^N + \beta E_i(V_i^U(m))$$

Note also, suppose there is a strictly positive probability such a consumer purchases a new unit from a different manufacturer. Then the firm could slightly lower P_{jt1}^{C} and increase its profits. Hence, all such consumers must purchase new units from firm j.

Now consider a firm that is choosing P_{jt2}^{C} and there are consumers in period t who own a used unit of the firm's product at the beginning of period t. By assumption $P_{jt2}^{C} \leq P_{jt1}^{C}$ and also by assumption there is a unique optimal value (see footnote 6). Call this optimal value P′′. Further, suppose $P'' = P' + \Delta$ and there is a strictly positive probability that a consumer who owns a used unit of firm j's product at the beginning of period t purchases from a different manufacturer or purchases nothing. Then the firm could slightly lower P_{jt2}^{C} and increase its profits. Hence, all such consumers either maintain their used units or purchase new units from firm j which, in turn, means (A3) reduces to (A5).

(A5) $$V_i^U(m) = \max\{v_i + \Delta - m + \beta V_i, v_i + \Delta - P'' - m^N + \beta E_i(V_i^U(m))\}$$

Consider a consumer born in period t who maintains a used unit in any period t in which he or she owns a used unit with maintenance realization m, $m \leq m'$, and purchases a new unit at cost c and m^N units of maintenance otherwise. Let $k_t^*(m')$ be the expected present discounted value evaluated in period t of the costs incurred by such a consumer. Also, analogously define $k_t^C(m')$ for the case in which a new unit is purchased from some firm j rather than being purchased at cost c. For notational convenience, in what follows let $k_t^*(m') = k^*(m')$, $k_{t+1}^*(m') = k'^*(m')$, $k_t^C(m') = k^C(m')$, and $k_{t+1}^C(m') = k'^C(m')$. Finally, let B_i be the present discounted value evaluated in period t of the stream of gross benefits of a consumer born in period t who consumes a new or used unit produced by some firm j (with appropriate levels of maintenance) in every period starting in period t.

Consider again a consumer who owns a used unit at the beginning of a period and the consumer's decision concerning whether to maintain or replace the unit. (A5) tells us that for each such consumer i there is a value m_i^C defined by (A6) such that the consumer maintains the unit if $m \leq m_i^C$ and purchases a new unit if $m > m_i^C$ (see footnote 13).

(A6) $$m_i^C = P'' + m^N - \beta[E_i(V_i^U(m)) - V_i]$$

From above we know that $E_i(V_i^U(m)) = B_i + \Delta - k'^C(m_i^C)$, while V_i for this consumer can be written as $V_i = B_i + \Delta - (P' + \Delta) - m^N - \beta k'^C(m_i^C)$. In turn, this yields that $E_i(V_i^U(m)) - V_i = (P' + \Delta) + m^N - (1-\beta)k'^C(m_i^C)$. But we know that m_i^C must maximize $E_i(V_i^U(m))$ which, given $E_i(V_i^U(m)) = B_i + \Delta - k'^C(m_i^C)$, means $k'^C(m_i^C)$ does not vary with i. Further, since $E_i(V_i^U(m)) - V_i = (P' + \Delta) + m^N - (1-\beta)k'^C(m_i^C)$, we now have that $E_i(V_i^U(m)) - V_i$ does not vary with i. (A6) now reduces to (A7) for every such consumer i.

(A7) $$m_i^C = m^C = P'' + m^N - \beta[E_i(V_i^U(m)) - V_i]$$

We know $E_i(V_i^U(m))=B_i+\Delta-k'^C(m^C)$ while $V_i=B_i+\Delta-(P'+\Delta)-m^N-\beta k'^C(m^C)$. Hence, (A7) yields (A8).

(A8) $$m^C=P''+m^N-\beta(P'+\Delta)-\beta m^N+\beta(1-\beta)k'^C(m^C)$$

By the definition of m* we have (A9).

(A9) $$m^*=c+m^N-\beta[E_i(V_i^U{}^*(m))-V_i^*],$$

where V_i^* and $V_i^U{}^*(m)$ are the value functions in the benchmark case. We know $E_i(V_i^U{}^*(m))=B_i+\Delta-k'^*(m^*)$ while $V_i^*=B_i+\Delta-c-m^N-\beta k'^*(m^*)$. Hence, (A9) can be written as (A10).

(A10) $$m^*=c+m^N-\beta c-\beta m^N+\beta(1-\beta)k'^*(m^*)$$

(A8) and (A10) yield (A11).

(A11) $$m^C-m^*=P''-\beta(P'+\Delta)-(c-\beta c)+\beta(1-\beta)(k'^C(m^C)-k'^*(m^*))$$

Let π^U be the present discounted value of the profit stream from period t forward of a durable-goods producer selling to a consumer who owns a used unit of the firm's product at the beginning of period t. P'' will be chosen to maximize $p(P'')[(P''-c)+\beta\pi^U]+(1-p(P''))\beta(P'+\Delta-c+\beta\pi^U)$, where $p(\cdot)$ is the probability the consumer purchases a new unit from the firm in period t as a function of the unit's price. Since P'' maximizes this expression and $P'+\Delta-c+\beta\pi^U>\pi^U$, we have $P''>c$. Given $P'+\Delta>c$, $P''>c$, and $k'^*(m)$ is the minimum value for $k'^*(\cdot)$, we know $k'^C(m^C)>k'^*(m^*)$.

Suppose $P''=P'+\Delta$. Given $P'+\Delta>c$ and $k'^C(m^C)>k'^*(m^*)$, (A11) yields $m^C>m^*$. Now consider the case $P''<P'+\Delta$. As stated before, P'' is chosen to maximize $p(P'')[(P''-c)+\beta\pi^U]+(1-p(P''))\beta(P'+\Delta-c+\beta\pi^U)$. Given this and $P''<P'+\Delta$, P'' must satisfy the following first-order condition.

(A12) $$p(P'')+[dp(P'')/dP'')](P''-c+\beta\pi^U)-[dp(P'')/dP'']\beta(P'+\Delta-c+\beta\pi^U)=0$$

Since $p(P'')>0$ and $dp(P'')/dP''<0$, (A12) yields

(A13) $$P''-\beta(P'+\Delta)-(c-\beta c)+\beta(1-\beta)\pi^U>0.$$

Suppose $m^C=m^*$. Then $k'^C(m^C)-k'^*(m^*)=\pi^U$. This means (A13) contradicts (A11) so therefore $m^C\neq m^*$. Suppose $m^C<m^*$. Then $k'^C(m^C)-k'^*(m^*)>\pi^U$. But then (A13) again contradicts (A11). Hence, $m^C>m^*$.

Now consider firm j that starts selling new units in period t. Given the sales of the firm as described above and competition, the present discounted value of expected profits from selling to any specific consumer in period t and later must equal exactly zero. Call this value π^N. We know that $\pi^N+EU_i^C=B_i-k^C(m^C)$. Given $\pi^N=0$, we have $EU_i^C=B_i-k^C(m^C)$ while in the benchmark case we have $EU_i^*=B_i-k^*(m^*)$. A consumer in each case will start purchasing durable units in the period he or she is born as long as $EU_i^C>0$ or $EU_i^*>0$ since given the pricing strategies of the firms waiting will only lower the present discounted value of the consumer's net benefits (see footnote 13). Given $k^C(m^C)>k^*(m^*)$ by the fact that $m^C\neq m^*$, we have $v_L^C>v_L^*$ (while $v_L^C<V$ follows immediately from $V>c+m^N$), which in turn yields $EU_i^M<(=)EU_i^*$ for all i for whom $v_i>(\leq)v_L^*$.

To complete our demonstration that there is an equilibrium that satisfies $0<v_L^*<v_L^C$, $m^C>m^*$, and i) through vi), all we need show is that the above behavior is consistent with our initial suppositions. First, suppose we now allow secondhand-market trade. Consider any pair of consumers i and j and suppose that all other consumers and all firms follow the strategies described above. Clearly, there is no

return for consumers i and j to deviate from the strategies above by trading with each other on the secondhand market. Second, we need to show that there is a value for P', $c-\Delta<P'<c$, that satisfies a zero-profit condition. Suppose $P'=c$. Then, noting that c' is arbitrarily close to c, given the above described behavior each firm that sells a unit for the first time earns strictly positive expected profits. Suppose $P'=c-\Delta$. Then given the above described behavior each firm that sells a unit for the first time earns strictly negative expected profits. Hence, since the expected profits associated with selling new units for the first time is a continuous function of P', there must be a value for P', $c-\Delta<P'<c$, consistent with zero expected profits.

The final step is to argue that there does not exist an equilibrium that does not satisfy $0<v_L^*<v_L^C$, $m^C>m^*$, and i) through vi). Any such equilibrium would need to violate at least one condition related to one of the posited conditions that we started with. One possibility is that there is never secondhand-market trade and consumers first purchase new durable units from firms that did not sell in the past, but newly-born consumers who participate in the durable-goods market do not all purchase new units in their first period at a price P', $c-\Delta<P'<c$, from firms that first offer new units in that period. First, they could not all purchase at a price greater than or equal to c or at a price less than or equal to $c-\Delta$ because this would violate the zero-profit condition. Second, it could not be the case that in some periods newly born consumers purchase new units at P' while in other periods they purchase at $P^{\#}$, $P^{\#}\neq P'$. This is because one of these prices would have to violate the zero-profit condition. Third, it could not be the case that there is a period in which some newly-born consumers purchase at P' while others purchase at $P^{\#}$, $P^{\#}\neq P'$. The reason is that the prices these consumers would face in later periods would be independent of whether the initial unit was purchased at P' or $P^{\#}$, so all such consumers would choose the lower price. Fourth, for reasons stated earlier, it could not be the case that some consumers first purchase new units after their first period.

A second possibility is that there is never secondhand-market trade, but not all consumers who participate in the durable-goods market first purchase from firms that did not sell new units in the past. The reason this is never true in equilibrium is related to arguments above. Because of the switching cost, we know that firms that did not sell in the past will be willing to sell new units at a price less than c and earn zero expected profits on the sales. In turn, also because of the switching cost, it cannot be optimal for a firm that sold in the past to match this price because it could earn strictly positive profits by charging a higher price and only selling to consumers who purchased from the firm in previous periods. Finally, the last possibility is that there is secondhand-market trade. Because a consumer's value for v_i does not affect the cost of consuming a used unit with a given maintenance requirement rather than a new unit, in this model there is no efficiency reason for a unit to change hands as it ages. Combining this with the ε cost of trading on the secondhand market means there is no secondhand-market trade in equilibrium.

Proof of Proposition 2: Pick any c′ (>c) such that $V>c'+m^N$ holds. Below, we first prove a variant of Proposition 2, call it Proposition 2', in which everything is the same as in Proposition 2 except that i) and iii) are replaced by i)' and iii)' respectively, defined as follows:

i)' For every firm j and period t, t≥2, if firm j sold new units in the first period then $P_{jt1}^M+p_{jt}^N=P^+<c+m^N$ and $P_{jt2}^M+p_{jt}^N=P_{jt3}^M+p_{jt}^N=P^++\Delta$, while $P_{j11}^M+p_{j1}^N=P^++c'-c$. Also, no firm starts production after the first period.

iii)' Each consumer i born in period t for whom $v_i>v_{Lt}^*$ ($v_i\le v_{L2}^*$) purchases a new unit and m^N units of maintenance in period t from the same durable-goods producer (never purchases new units, used units, or maintenance), and each consumer i born in period 1 for whom $v_{L2}^*<v_i\le v_{L1}^*$ purchases a new unit and m^N units of maintenance for the first time in period 2 from the same durable-goods producer, where $v_{L2}^*=v_{L3}^*=\ldots=v_{L\infty}^*\equiv v_L^*<v_{L1}^*\equiv v_L^*+c'-c$.

The plan of the proof is as follows. We first define the following set of strategies as Strategy Set M. In this set of strategies every durable-goods producer monopolizes the maintenance market for its own product and includes a no-trade clause in its sales of maintenance in every period. Also, prices are defined by i)' and ii), where P^+ satisfies a zero-profit condition. In what follows we first show that the outcome described in Proposition 2' is an equilibrium outcome given this set of strategies, and then show given this that Strategy Set M constitutes an equilibrium set of strategies.

Consider first consumer i who is born in period t (≥2) and does not own a used unit at the beginning of period t′ and did not consume a unit of any firm's product in the previous period. The consumer has two relevant options. The consumer can purchase nothing or purchase a new unit and m^N units of maintenance from one of the durable-goods sellers. That is, EU_i^M is given by (A14).

(A14) $$EU_i^M=\max\{0+\beta EU_i^M, v_i-P^++\beta E_i(V_i^U(m))\}$$

Let v_L^M be such that $v_L^M-P^++\beta E_i(V_i^U(m))=0$ and suppose $E_i(V_i^U(m))$ is weakly increasing in v_i. Then (A14) tells us that a best response for this consumer is to purchase a new unit and m^N units of maintenance this period if $v_i>v_L^M$ and purchase nothing if $v_i\le v_L^M$. Further, we know that $E_i(V_i^U(m))$ must be weakly increasing in v_i since, if it were not, there would exist an individual i who could increase $E_i(V_i^U(m))$ by adopting the strategy of some individual i′, $v_{i'}<v_i$. This cannot be the case since it violates the idea that individual i's strategy is a best response.

Now consider consumer i who is born in period t (≥2) and does not own a used unit at the beginning of period t′ but consumed a unit of firm j's output in the previous period. This consumer has three relevant options. The consumer can purchase nothing, purchase a new unit and m^N units of maintenance from firm j at $P^++\Delta$, or purchase a new unit and m^N units of maintenance from a different firm at P^+. That is, V_i is given by (A15).

(A15) $$V_i=\max\{0+\beta EU_i^M, v_i+\Delta-(P^++\Delta)+\beta E_i(V_i^U(m)), v_i-P^++\beta E_i(V_i^U(m))\}$$

(A15) tells us that a best response for consumer i is to purchase a new unit and m^N units of maintenance from firm j as long as $v_i-P^+ +\beta E_i(V_i^U(m))>\beta EU_i^M$ and we know this condition holds from above. This implies that $V_i=v_i-P^+ +\beta E_i(V_i^U(m))$.

Now consider consumer i who is born in period t (≥2) and owns a used unit of firm j's output at the beginning of period t′ with maintenance realization $m_{it'}^U$. This consumer has four relevant options. The consumer can purchase nothing, purchase $m_{it'}^U$ units of maintenance from firm j at $p_{jt'}^U(m_{it'}^U)$, purchase a new unit and m^N units of maintenance from firm j at $P^+ +\Delta$, or purchase a new unit and m^N units of maintenance from a different firm at P^+. That is, $V_i^U(m)$ is given by (A16).

(A16) $V_i^U(m)=\max\{0+\beta EU_i^M, v_i+\Delta-p_{jt'}^U(m)+\beta V_i, v_i+\Delta-(P^+ +\Delta)+\beta E_i(V_i^U(m)), v_i-P^+ +\beta E_i(V_i^U(m))\}$

Since $V_i\le E_i(V_i^U(m))$ and $V_i=v_i-P^+ +\beta E_i(V_i^U(m))$, (A16) implies $V_i=E_i(V_i^U(m))$. Then (A16) tells us that a best response for consumer i is to maintain whenever $m_{it'}^U<m^*$ and purchase a new unit and m^N units of maintenance from firm j whenever $m_{it'}^U>m^*$, and when $m_{it'}^U=m^*$ either behavior can be a best response depending on the value for $p_{jt'}^U(m^*)$.

To complete the first part of the proof for t≥2 all we need show is that $v_L^M=v_L^*$ and $EU_i^M=EU_i^*$ for all i. Using notation from the proof of Proposition 1, we know that $EU_i^*=B_i-k^*(m^*)$ for any consumer i for whom $v_i>v_L^*$ while $EU_i^*=0$ for any consumer i for whom $v_i\le v_L^*$, where v_L^* is such that an individual for whom $v_i=v_L^*$ satisfies $B_i-k^*(m^*)=0$. Similarly, given P^+ satisfies a zero-profit condition, the above results tell us that $EU_i^M=B_i-k^*(m^*)$ for any consumer i for whom $v_i>v_L^M$ while $EU_i^M=0$ for any consumer i for whom $v_i\le v_L^M$, where v_L^M is also such that an individual for whom $v_i=v_L^M$ satisfies $B_i-k^*(m^*)=0$. We thus have $v_L^M=v_L^*$ and $EU_i^M=EU_i^*$ for all i. This implies that, given Strategy Set M, the outcome described in Proposition 2' is an equilibrium outcome for consumers who are born in any period t≥2. Through an analogous argument, it can be shown that, given Strategy Set M, the outcome described in Proposition 2' is an equilibrium outcome for consumers who are born in period 1 (details are available upon request).

We now show that Strategy Set M constitutes an equilibrium set of strategies. First, consider a firm in period t for whom there are individuals that consumed a unit of the firm's product in the previous period and suppose that all other firms employ the strategies described in Strategy Set M. Given the strategies of the other firms and assuming the consumer best responses described above, the firm cannot earn strictly positive profits from selling to consumers who did not consume a unit of the firm's product in the previous period. In turn, given this, the firm will achieve the highest possible profits starting in period t if it earns zero profits from this set of consumers and extracts all the potential surplus from the consumers who consumed a unit of the firm's product in the previous period. By the latter we mean that each such consumer must be indifferent between purchasing from the firm and purchasing from another firm in period t and all later periods and each such consumer must behave in an efficient fashion in period t and all later periods. Since following the strategy described in Strategy M satisfies this given the consumer best responses described above, this strategy must be a best response.

Second, consider a firm in period t for whom there are not individuals who consumed a unit of the firm's product in the previous period, and suppose that the firm produced a strictly positive amount of output in a past period and that all other firms employ the strategies described in Strategy Set M. Given the strategies of the other firms and assuming the consumer best responses described above, the firm cannot earn strictly positive profits from selling to any group of consumers this period. In turn, given this, a best response is any strategy that earns zero expected profits starting in period t. Since from above we know that if the firm sells new units this period it will not have an incentive to deviate from the strategy described in Strategy Set M in later periods, following the strategy described in Strategy Set M this period must be a best response.

Finally, consider a firm in period t for whom there are no individuals who consumed a unit of the firm's product in any past period and suppose that all other firms employ the strategies described in Strategy Set M. First suppose $t \geq 2$. Since the firm did not produce a strictly positive amount of output in any past period, given the strategies of the other firms and assuming the consumer best responses described above, the firm earns strictly negative profits from selling to any group of consumers this period. Next suppose $t=1$. Then, given the strategies of the other firms and assuming the consumer best responses described above, the firm cannot earn strictly positive profits from selling a strictly positive amount of output this period. In turn, given this, a best response is any strategy that earns zero expected profits starting in period 1. Since from the analysis presented in the previous paragraph we know that if the firm sells new units this period it will not have an incentive to deviate from the strategy described in Strategy Set M in later periods, following the strategy described in Strategy Set M this period must be a best response. Hence, Strategy Set M constitutes an equilibrium set of strategies, and in the equilibrium outcome no firm starts production after the first period.

Now pick any v_i such that $v_i > v_{L2}^*$. We can always pick $c'(>c)$ such that $v_i > v_{L1}^*$. This in turn implies that in the limit as c' approaches c from above, i)' and iii)' can be replaced by i) and iii) respectively in the description of the nature of the equilibrium. Hence, in the limit as c' approaches c from above, there exists an equilibrium characterized by i) through vi), where every durable-goods producer monopolizes the maintenance market for its own product and includes a no-trade clause in its sales of maintenance in every period t, $t \geq 1$. Furthermore, it can be shown that every equilibrium exhibits this feature (details are available upon request).

Proof of Proposition 3: Pick any c' $(>c)$ such that $V > c' + s(d^*) + m^N$ holds. Let us for now focus on a set of equilibria in which no firms commit to future prices. Then, through an argument similar to the main argument in the proof of Proposition 2' (which was defined in the previous proof) it can be shown that substituting $c+s(d^*)$ and $c'+s(d^*)$ for c and c' respectively in i)' of Proposition 2', every equilibrium is characterized by i)' through vi) of Proposition 2', where in each equilibrium every durable-goods producer chooses durability level d^*, monopolizes the maintenance market for its own product, and

includes a no-trade clause in its sales of maintenance in every period t, $t \geq 1$ (details are available upon request).

We now show that there exists no equilibrium in which a firm commits in the first period of its operation to future prices and sells a strictly positive number of new units. Suppose, to the contrary, there exists an equilibrium in which firm j commits in period 1 to the sequence of future prices for new units $\{p_t\}$ (t=1, 2, 3, …), and sells a positive number of new units in period 1. Let EU_k' denote the present discounted value evaluated in period 1 of the expected net benefits received by consumer k who purchases a new unit from firm j in period 1. We have that $EU_k'=EU_k^*$ must hold in the equilibrium, where, as in the analysis of the original model, EU_i^* denotes the present discounted value evaluated in the period the consumer is born of the expected net benefits received by consumer i in the benchmark case (here, in the benchmark case, the maintenance market is competitive, each producer can commit in the first period to the prices it will charge in subsequent periods for a new unit of output, and the level of product durability is fixed at d*). To see this, consider a firm that sells a positive number of new units in period 1 without making a commitment to future prices. Given the result described in the previous paragraph, by monopolizing the maintenance market and including a no-trade clause in its sales of maintenance, the firm can earn zero overall expected profits while consumer i who purchases a new unit from the firm in the first period receives EU_i^* as the present discounted value of the expected net benefits. Since EU_i^* is the maximum possible amount that consumer i can receive given the zero-profit condition, $EU_k'=EU_k^*$ must hold for firm j to sell a strictly positive number of new units in period 1.

In the equilibrium firm j chooses $d_j=d^*$ (>0) in period 1, and in every future period consumer k consumes a unit produced by firm j and makes efficient replacement/maintenance decisions. That is, if consumer k owns a used unit in the beginning of period t, she consumes the used unit with the required level of maintenance if $m_{kt} \leq m^*$ and purchases a new unit if $m_{kt}>m^*$, where the consumer is indifferent between replacement and maintenance if $m_{kt}=m^*$. This implies that $v_k+\Delta-m^*+\beta V_{t+1}=V_t$ holds for all $t>1$, where V_t denotes the value of consumer k at the beginning of period t when she does not own a used unit. We then have that $\beta(V_{t+1}-V_t)=V_t-V_{t-1}$ for all t (>2) where $0<\beta<1$. Suppose $V_{t+1}-V_t<0$, which implies that $\lim_{t\to\infty} V_t=-\infty$. Then consumer k switches to another firm at a certain period, and hence $EU_k'=EU_k^*$ cannot hold. Now suppose $V_{t+1}-V_t>0$, which implies that $\lim_{t\to\infty} V_t=\infty$. We then have $\lim_{t\to\infty} p_t=-\infty$, which violates $p_t \geq 0$ for all t. Therefore $V_t=V_{t+1}\equiv V^*$ holds for all $t>1$.

Note that in the equilibrium (A17) holds.

$$V_1=v_k-p_1+\beta\left[\int_0^{m^*} (v_k+\Delta-m+\beta V_3)f(m)dm+\int_{m^*}^{\infty} V_2 f(m)dm\right] \quad \text{(A17)}$$

On the other hand, we have (A18) from the analysis of the benchmark case (details are available upon request).

$$EU_k^*=v_k-(c'+s(d^*))+\beta\left[\int_0^{m^*} (v_k+\Delta-m+\beta V^*)f(m)dm+\int_{m^*}^{\infty} V^* f(m)dm\right] \quad \text{(A18)}$$

Noting that $V_2=V_3=V^*$ and $V_1=EU_k^*$, the comparison of (A17) and (A18) yields $p_1=c'+s(d^*)$ $(>c')$. This implies that firm j can make a strictly positive profit by choosing $d_j=0$ in period 1, which in turn implies that there exists no equilibrium in which a firm commits in the first period of its operation to future prices and sells a strictly positive number of new units.

Finally, an argument analogous to the one presented in the last paragraph of the proof of Proposition 2 completes the proof.

Proof of Proposition 4: In what follows we will show that there does not exist an equilibrium in which a firm sells a strictly positive number of new units in a certain period and does not monopolize the maintenance market in the next period. Suppose, to the contrary, that there exists an equilibrium in which firm k sells a strictly positive number of new units in period t-1 and does not monopolize the maintenance market in period t. Let $\pi_{ji}(r)$ denote the present discounted value of firm j's expected profits from consumer i who at the beginning of a period owns one of firm j's used units that requires r units of replacement parts for maintenance. Also let π_{ji} denote the present discounted value of firm j's expected profits from consumer i who in the previous period consumed one of firm j's used units. Let P_{Rkt} denote the price firm k charges for a replacement part in period t, and P_{kt}' denote the price at which firm k sells new units in period t to consumers who at the beginning of period t own one of firm k's used units. Given the switching costs, in the equilibrium every consumer i who purchased a new unit from firm k in period t-1 consumes one of firm k's units in every period t′, t′=t,t+1,…,∞. Hence (A19) holds for every consumer i who purchased a new unit from firm k in period t-1.

(A19) $$E_i(\pi_{ki}(r))=\int_0^{r'}[(P_{Rkt}-c_r)r+\beta\pi_{ki}]h(r)dr+\int_{r'}^{\infty}[(P_{kt}'-c)+\beta E_i(\pi_{ki}(r))]h(r)dr\equiv\Pi_i$$

Given $r^U\in(0,\infty)$ and $c+r^Nc_r>0$, in the equilibrium firm k chooses P_{Rkt} such that a strictly positive measure of consumers maintain their used units in period t, which implies $r'>0$. Now let $p_{jt}^U(r)$ denote the price that durable-goods producer j charges in period t for one unit of service and r units of replacement parts to individuals who own used units of the firm's product at the beginning of period t. Suppose that firm k monopolizes the maintenance market in period t, chooses $p_{kt}^U(r)=c_s+r'P_{Rkt}$ for all $r\le r'$ and $p_{kt}^U(r)>c_s+r'P_{Rkt}$ for all $r>r'$, and sells new units at the price of P_{kt}' for consumers who at the beginning of period t own a used unit produced by firm k. Then the present discounted value evaluated in period t of firm k's expected profit from each consumer i who at the beginning of period t owns one of firm k's used units is given by (A20).

(A20) $$\int_0^{r'}[(r'P_{Rkt}-rc_r)+\beta\pi_{ki}]h(r)dr+\int_{r'}^{\infty}[(P_{kt}'-c)+\beta E_i(\pi_{ki}(r))]h(r)dr\equiv\Pi_i'$$

Given $r'>0$ we have $\int_0^{r'}(r'P_{Rkt}-rc_r)h(r)dr>\int_0^{r'}(P_{Rkt}-c_r)rh(r)dr$, which implies $\Pi_i'>\Pi_i$. This implies that firm k is strictly better off by monopolizing the maintenance market in period t.

Hence there does not exist an equilibrium in which a firm sells a strictly positive number of new units in a certain period and does not monopolize the maintenance market in the next period. Given this, through the procedure analogous to the proof of Proposition 2 (details are available upon request) it can be shown that in every equilibrium every durable-goods producer monopolizes the maintenance market for its own product and includes a no-trade clause in its sales of maintenance in every period t, $t \geq 1$.

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