COMPETITION, MONOPOLY, AND AFTERMARKETS

by

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ABSTRACT

Consider a durable goods producer that has the option of monopolizing an aftermarket such as repair for its own product. An important question is whether such monopolization reduces welfare? We show that the anwer to this question is frequently no. In particular, we explore three models that illustrate various ways in which aftermarket monopolization can reduce inefficiencies and thus increase social welfare and frequently also consumer welfare. Our paper shows that efficiency enhancing aftermarket monopolization may be much more common than previous literature suggests.

I. INTRODUCTION

A series of court cases concerning firms such as Kodak, Data General, and Xerox, have focused attention on aftermarkets. The term aftermarkets refers to markets for complementary goods and services such as maintenance, upgrades, and replacement parts used in conjunction with durable goods. A typical allegation is that the durable goods producer stops alternative producers from selling the complementary product with the result that the original durable goods producer monopolizes the aftermarket. For example, in a 1992 Supreme Court case, Kodak refused to sell spare parts to alternative maintenance suppliers with the result that consumers of Kodak's products were forced to purchase maintenance from Kodak. In this paper we show that various behaviors that hurt competition in aftermarkets can, in fact, serve to reduce inefficiencies that can arise in markets for new equipment and aftermarkets.

Our basic argument is that a competitive aftermarket does not always yield an efficient outcome, and when this is the case a durable goods producer may behave in a manner that hurts competition in the aftermarket but which improves overall efficiency. As a simple example, consider a monopolist that sells a durable good that requires maintenance. If the monopolist prices its output above marginal cost while the maintenance market is competitive, the result is not an efficient outcome. Rather, in deciding whether to maintain or replace used units, because new units are priced above marginal cost while maintenance is priced at marginal cost, consumers will have an incentive to maintain their used units inefficiently often. The result is that the act of monopolizing the maintenance market by the durable goods monopolist can increase social welfare by reducing the inefficient maintenance decisions.

In this paper we present three models that extend the intuition from this simple maintenance example. We begin with a model related to the previous discussion. In our model competitive durable goods sellers have the option of monopolizing the maintenance markets for their own products or allowing maintenance markets to be competitive. It is efficient for some used units to be maintained and others replaced. Further, although we assume competition in the new-unit market which is consistent with the type of setting considered by the Supreme Court in the 1992 *Kodak* decision, there is market power in the market for replacement units. This is the case because, also consistent with the *Kodak* case, we assume consumer switching costs. By consumer switching costs we mean costs of switching between manufacturers when a consumer decides to replace a used unit. [1]

Our analysis yields the following. First, if maintenance markets are competitive, then consumers do not make efficient maintenance decisions. The reason is that, because maintenance is priced competitively while market power in the replacement market due to the switching costs means replacement units are priced above cost, consumers maintain their used units inefficiently often. Second, because of the inefficient maintenance decisions associated with competition in the maintenance market, in equilibrium durable goods sellers monopolize the maintenance markets for their own products which eliminates the inefficiency. In turn, the competition for new goods guarantees that consumers benefit from the elimination of the inefficiency, so that consumer and social welfare increase.

Our second model extends our analysis to the set of empirically significant cases that involve a durable good with product improvements and upgrades. We again consider a two-period competitive durable goods model characterized by switching costs, where as indicated the model is characterized by product improvements and upgrades. Product improvement means a unit produced in the second period is of higher quality than a unit produced in the first, while an upgrade refers to a complementary product purchased in the second period used to increase the functionality or quality of a used unit. We further assume that in the second period a new unit has superior functionality to an upgraded used unit, and that there is heterogeneity concerning the value consumers place on this superior functionality. As a result, in the second period it is efficient for some consumers to purchase new units and others to upgrade.

Our analysis shows that, given a competitive supply of upgrades, some durable goods producers monopolize the upgrade market for their own durable products in the second period with the result being increased efficiency. The logic here is related to the basic logic of our first analysis. Due to switching costs, each durable goods producer has market power in the second period in selling new units to individuals who purchased new units from the firm in the first period. Because of this market power, a competitive price for upgrades results in too many consumers purchasing upgrades in the second period rather than purchasing new units. There is, however, a new factor that arises in this model because of its richer specification for consumer heterogeneity. That is, given competition in the upgrade market, consumers who purchase new units in the second period subsidize those who upgrade, where by this we

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[1] There is an extensive literature that investigates models characterized by consumer switching costs. Papers in this literature include Klemperer (1987,1989) and Farrell and Shapiro (1988,1989). Klemperer (1995) surveys the literature.

mean that the premium paid by consumers who purchase new units in period 2 reduces the new-unit price for all consumers in period 1. The subsequent result is that, if durable goods producers have the option to eliminate competition in the upgrade market by monopolizing it, some of the firms monopolize the upgrade markets for their own products in the second period which, in combination with competition in period 1, eliminates both the consumer cross-subsidization and the inefficient upgrade decisions.

To summarize our first two models, the basic idea is that the presence of switching costs can cause competitive aftermarkets to become inefficient and aftermarket monopolization can serve to reduce this inefficiency. The first step of the argument is that, given competition the aftermarket product is priced at marginal cost, but the switching cost gives a first-period seller of the durable good market power in the second-period market for replacement units. In turn, this market power means the second-period price for a replacement durable unit is above marginal cost. But we know that when one product is priced at marginal cost while the price of a substitute is above marginal cost, the result is that consumers inefficiently substitute towards the good priced at marginal cost.

The second step of the argument is that allowing aftermarket monopolization can serve to reduce this inefficiency. That is, to the extent that after monopolizing the aftermarket in the second period a durable goods producer is able to capture any increase in second-period social surplus through optimally pricing replacement units and the aftermarket product, the firm will want to make that second-period social surplus as large as possible or, in other words, eliminate the distortion discussed in the above paragraph. Finally, because of our assumption of competition in the first-period market for durable units, this increase in second-period surplus is captured by consumers through a lower first-period price for durable units. So aftermarket monopolization increases both social welfare and consumer welfare.

Our third analysis deals with the case of remanufactured parts, where a remanufactured part is a used part that has gone through a reconditioning process that makes the part similar in functionality to a new part. Remanufactured parts are common in the service and maintenance of a large variety of durables such as automobiles, refrigerators, and computers. A practice that has drawn antitrust scrutiny is that when a broken or worn out part is replaced by the original producer with a new or remanufactured part, the producer sets a price for the part and then offers a discount off this price that is called the "core charge". The core charge is a discount a producer gives to a consumer when the consumer returns the broken or worn out part to the producer and the part is in a condition that makes remanufacturing possible. The behavior that has drawn antitrust scrutiny is the common practice of original producers of setting the core charge significantly above the scrap price for the returned part. This behavior has drawn scrutiny because the high core charge makes it costly for rival remanufacturers to obtain the worn out parts needed for the reconditioning process.[2]

We consider a three-period model characterized by a durable goods monopolist, where there is a part associated with each used unit that sometimes wears out and it is then efficient to replace the part with either a new part or a remanufactured part. Consistent with many of the products for which remanufacturing is important, we assume there is competition in the remanufacturing of worn out parts. Also, due to economies of scope between the production of new parts and the remanufacturing of worn out parts, the monopolist has a cost advantage over rivals in remanufacturing. Analysis shows that the monopolist in the new-unit market sets the core charge above the scrap price of a worn out part and in this way monopolizes the market for remanufacturing. However, in our analysis this behavior is not associated with a deadweight loss due to the monopoly pricing of remanufactured parts. Rather, when the durable goods monopolist becomes the sole remanufacturer social welfare rises because worn out parts are remanufactured in the lowest cost fashion.

Most previous researchers who have considered aftermarket monopolization have argued that the behavior typically reduces social welfare because the monopoly pricing in the aftermarket creates a standard deadweight loss in that market. Our analysis shows that there is another possibility. In various settings, such as when there are switching costs associated with the purchase of replacement units, such behavior can serve to eliminate a social welfare cost that arises when there is competition in the aftermarket. From a public policy perspective this is a crucial difference because, in a setting where the behavior serves to eliminate a social welfare distortion, the behavior should typically be allowed rather than prohibited.

A few authors have previously put forth efficiency explanations for aftermarket monopolization, although the specifics of those arguments are different than the arguments put forth here. For example, Chen and Ross (1999) focus on a competitive setting in which aftermarket monopolization stops consumer cross-subsidization and improves efficiency by moving maintenance choices towards efficient levels, while Elzinga and Mills (2001) consider a durable goods oligopoly setting where aftermarket

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[2] See, e.g., Bepco Inc. et al. v. Allied Signal Inc. et al., no. 6:96CV00274. Carlton served as an expert for Allied Signal.

monopolization is required to achieve Ramsey optimal pricing (both papers are described in more detail in Section V).

The contribution of our paper is to provide a number of additional settings in which aftermarket monopolization increases rather than decreases social welfare. And, in turn, we believe these additional settings show that aftermarket monopolization that improves welfare may be much more common than previous literature suggests.

II. DURABLE GOODS COMPETITION AND MONOPOLY MAINTENANCE

This section's analysis is related to earlier papers such as Schmalensee (1974), Su (1975), and Rust (1986) that consider durable goods monopoly models with competitive maintenance markets. These papers show that, because the durable goods monopolist's price is above the marginal cost of production while maintenance is priced competitively, consumers sometimes maintain used units that would be more efficiently replaced. Tirole (1988) shows that an extension of these analyses yields a rationale for why a durable goods monopolist would monopolize the maintenance market for its own product (see his reader exercise on page 181). That is, because competitive maintenance means consumers maintain their used units too often, the monopolist can increase its profits by monopolizing the maintenance market and eliminating the distortion.

This section extends the above argument to a setting in which in the first period, i.e., prior to consumers making their initial purchase decisions, the new-unit market is perfectly competitive. The key assumption is that, as was true in the *Kodak* case, the new-unit market is characterized by consumer switching costs.[3] By consumer switching costs we mean that a consumer who owns a used unit initially

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[3] The allegations against Kodak in the 1992 case contained a number of detailed accounts of switching costs faced by consumers of Kodak's products. 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 also state that similar systems to the one described above were found in a variety of places 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) produced by firm j prefers to replace that unit with a new unit also produced by j. We show that, due to switching costs, the above argument applies even though in the first period the new-unit market is perfectly competitive. The basic idea is that with a competitive maintenance market consumers overmaintain their used units because replacement units are priced above the marginal cost of production, while a firm that monopolizes the maintenance market for its own product avoids the inefficiency.

A) The Model

We consider a two-period setting in which there are two perfectly competitive industries, where one produces a durable good while the other supplies maintenance for the good.[4] Each durable goods producer has a constant marginal cost of production equal to c and no fixed costs of production, where a unit lasts two periods. As described further below, for both new and used units the amount of maintenance purchased determines the gross benefit a consumer derives from the consumption of the good. Also, a used unit that is not used for consumption has a scrap value equal to zero.

Maintenance for a durable unit produced by firm j can be supplied either by a competitive maintenance producer or by firm j itself, where there are no fixed costs of supplying maintenance and the variable costs of supplying maintenance is one per unit. Note, since the maintenance industry is perfectly competitive, this means maintenance firms sell maintenance of level m at a price equal to m. We allow for two possibilities concerning the maintenance market. We first assume durable goods producers cannot stop consumers from purchasing maintenance from competitive maintenance firms. We then assume a durable goods producer can stop consumers of its product from purchasing maintenance from other firms and in this way can monopolize the maintenance market for its own product.

There is a continuum of nonatomic consumers whose total mass is normalized to one. We further assume consumers are heterogeneous in their valuations for the durable product and there are consumer switching costs. Specifically, in the first period each consumer i who purchases a new durable unit receives a gross benefit equal to v_i-$f(m_{i1})$, where m_{it} is the amount of maintenance purchased by consumer i in period t. If consumer i does not purchase a new durable unit his gross benefit equals zero.

[4] In Sections II and III we consider two-period models while in Section IV we consider a three-period model. In each case the basic argument can be made in an infinite period setting. But because the goal of this paper is to show a variety of settings in which aftermarket monopolization can improve welfare, we focus on the simpler settings. See Morita and Waldman (2007) for an analysis of an infinite period model similar to the one considered in this section which finds similar results, although that paper considers a simpler specification concerning how maintenance affects used-unit quality. Also, see footnote 26 for a related discussion.

Further, $f(m)>0$ for all $m\geq 0$, where $f'(0)=-\infty$, $f'(m)<0$ and $f''(m)>0$ for all $m\geq 0$. The distribution of v_is in the population is described by a density function g(.), where $g(v)>0$ for all $v\in[v_L,v_H]$ and $g(v)=0$ for all v outside of this interval. 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 the second period is more complicated both because it captures the switching cost and because the return to maintaining a used unit is stochastic. Let Δ denote the size of the switching cost, j_i be the producer of the durable unit consumed by individual i in the first period, and z_i denote the stochastic realization of the return to maintaining the used unit owned by individual i where the higher is z_i the lower is the return to maintaining rather than replacing the used unit. There are five possibilities. First, each consumer i receives a gross benefit equal to $v_i-f(m_{i2})$ from consuming a new durable unit produced by j_i. Second, he receives a gross benefit equal to $v_i-\Delta-f(m_{i2})$ from consuming a new durable unit produced by a different firm. Third, if consumer i did not consume a new unit in the first period, then the consumer receives a gross benefit equal to $v_i-f(m_{i2})$ from consuming a new durable unit produced by any manufacturer. Fourth, consumer i's gross benefit equals zero if he does not consume a durable unit in the second period.

The last possibility is that individual i consumes the used durable unit he consumed as new in the first period. In this case his gross benefit is $v_i-(1+z_i)f(m_{i2})$, where z_i is a random draw from the probability density function h(.). Further, we assume $h(z)>0$ for all $z\in(0,\infty)$, $h(z)=0$ for all z outside of this interval, and z_i is privately observed by consumer i and the firm that maintained the unit when it was new.[5] The role of this assumption is that it means that a firm that monopolizes the maintenance market for its own product knows whether it is efficient to maintain or replace a used unit and the efficient level of maintenance when maintaining the unit is efficient. We believe that assuming the first-period maintenance provider learns z_i is quite natural. This firm observes the machine on a regular basis in the first period and should know of any first-period malfunctions that might translate into higher maintenance requirements in the second period. We also assume $v_L-\Delta-f(0)>c$. This assumption ensures that all consumers purchase a new durable unit in the first period and consume either a new unit or a used unit in

[5] We also assume h(.) is such that, when the maintenance market is competitive, there is a unique second-period price for new units that maximizes second-period profits for a firm that sells a strictly positive number of new units in the first period. This assumption simplifies the statement of Proposition 1.

the second. We discuss this assumption further at the end of the analysis. We finally assume all firms and consumers are risk neutral and have a discount factor β, $0<\beta<1$.

The timing of the model is as follows. The first period consists of three stages. First, when monopolizing the maintenance market is an option, each durable goods producer decides whether or not to monopolize the maintenance market for its own product. Second, each durable goods producer chooses the sale price for a new unit of output (see footnote 10 for a discussion of what happens given leasing). At the same time, each durable goods producer that has monopolized the maintenance market for its own product chooses a price for each level of maintenance in the interval $(0,\infty)$. Third, each consumer makes his purchase decisions. The second period consists of two stages. First, each durable goods producer chooses a new-unit price.[6] Also, at the same time each durable goods producer that has monopolized the maintenance market for its own product chooses a maintenance price schedule, where the price schedule makes the maintenance price a function of both the level of maintenance purchased and the consumer's realization for z_i. Second, each consumer makes his purchase decisions. Note that we could introduce a third stage in which there is trade between consumers on the secondhand market, but this would not affect the results. Throughout we focus on Subgame Perfect Nash Equilibria which means that in the first period consumers correctly anticipate the equilibrium strategies of the firms.[7]

B) Analysis

The analysis proceeds in three steps. First, we briefly discuss the results of a benchmark analysis in which there are no consumer switching costs. Second, we assume there are switching costs and consider what happens when the maintenance market is competitive. Third, we consider what happens given switching costs when each durable goods producer has the option of monopolizing the maintenance market for its own product.

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[6] For the analysis of the second-period pricing game we assume free entry into the market for new durable units in the second period as well as the first. An alternative assumption that would serve the same role is that in the second period each durable goods producer can price discriminate between consumers who purchased the firm's product in the first period and other consumers.

[7] Note that although by focusing on Subgame Perfect Nash equilibria we are assuming that consumers in the first period correctly anticipate second-period strategies including second-period prices, this is in fact not a crucial feature of our analysis. That is, if we instead assumed that consumers in the first period simply considered first-period prices in making their purchase decisions and ignored whether or not a firm had chosen to monopolize its maintenance market, there would be no change in equilibrium behavior. Although see footnote 12 for an exception.

Suppose there are no consumer switching costs, i.e., $\Delta=0$, and the maintenance market is competitive. Because there are no switching costs, the price for a new unit of output is c in each period, while competitive maintenance means the price for m units of maintenance is m in each period. In this case, every consumer purchases a new durable unit in the first period and m_1^* units of maintenance, where $f'(m_1^*)=-1$. Also, the second period is characterized by a critical value for z, call it z*, such that the following holds. Consumers for whom $z_i>z^*$ replace their used units with new units and purchase m_1^* units of maintenance (so m_1^* units of maintenance is the efficient maintenance level for a new unit whether the unit is consumed in the first or second period). On the other hand, consumers for whom $z_i\leq z^*$ maintain their used units and purchase $m_2^*(z_i)$ units of maintenance, where $(1+z_i)f'(m_2^*(z_i))=-1$.[8] Let EU_i^* denote the present discounted value of consumer i's expected net benefits over the two periods in this case (since both markets are perfectly competitive, the expected profitability of a firm in each market equals zero). Note further that, because both markets are competitive and there are no switching costs, z* represents the first-best critical value for z and m_1^* and $m_2^*(z_i)$ represent the first-best maintenance levels.

We now assume there are switching costs, i.e., $\Delta>0$, and consider what happens when the maintenance market is competitive. Below P_{jt}^C denotes producer j's price for a new unit of output in period t in this case and EU_i^C denotes the present discounted value of the expected net benefits received by consumer i over the two periods in this case.

<u>Proposition 1</u>: Suppose the maintenance market is competitive and there are consumer switching costs. There exists a critical value z′, z′>z*, such that i) through v) describe the unique equilibrium.

i) $P_{j1}^C<c$ and $P_{j2}^C>c$ for every firm j that sells a strictly positive number of new units in the first period.

ii) In period 1 each consumer i purchases a new unit and m_1^* units of maintenance.

iii) In period 2 each consumer i for whom $z_i>z'$ replaces his used unit with a new unit purchased from firm j_i and purchases m_1^* units of maintenance.

iv) In period 2 each consumer i for whom $z_i\leq z'$ consumes his used unit and purchases

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[8] Throughout we assume that a consumer who receives the same second-period net benefit from maintaining his used unit as from replacing it prefers to maintain it. This assumption simplifies the statements of the propositions.

$m_2^*(z_i)$ units of maintenance.

v) $EU_i^C < EU_i^*$ for all i.

Proposition 1 tells us that an inefficiency arises given competitive maintenance and consumer switching costs. Specifically, $z' > z^*$ tells us that some consumers maintain their used units when it would be efficient for the units to be replaced. The logic is as follows. Think back to what happened in the absence of switching costs. In that case each durable goods producer charges c for new units in the second period. As a result, since the prices for maintenance and new durable units both equal the marginal cost of production, in the second period consumers make efficient choices concerning whether to maintain or replace their used units. Now consider what happens when switching costs are introduced. In that case each durable goods producer chooses a second-period price for new units strictly above c. The reason is that setting the second-period price equal to c results in second-period profits equal to zero, but because of switching costs each firm can earn positive second-period profits by choosing a second-period price above c. The result is that more consumers maintain their used units than is efficient.

The next step is to consider what happens when each durable goods producer has the option of monopolizing the maintenance market for its own product. Below P_{jt}^M denotes producer j's period-t new-unit price in this case and EU_i^M denotes the present discounted value of the expected net benefits received by consumer i over the two periods in this case. Also, when firm j monopolizes the maintenance market for its own product, $p_{jt}(m)$ denotes the price firm j charges for m units of maintenace in period t to an individual who consumes a new unit produced by j. Further, again considering the case where firm j monopolizes the maintenance market for its own product, $p_{j2}'(m,z_i)$ denotes the price firm j charges for m units of maintenance in the second period to an individual i who owns a used unit that he purchased from firm j in the first period.

<u>Proposition 2</u>: Suppose each durable goods producer has the option of monopolizing the maintenance market for its own product and there are consumer switching costs. Then every equilibrium is characterized by i) through vi), where in each equilibrium every durable goods producer with strictly positive production in the first period monopolizes the maintenance market for its own product.[9]

[9] There are multiple equilibria because the price functions are not uniquely defined.

i) $P_{j1}^{M}+p_{j1}(m_1^*)<c+m_1^*$ and $P_{j2}^{M}+p_{j2}(m_1^*)=c+m_1^*+\Delta$ for every firm j with strictly positive first-period production.

ii) $p_{j2}'(m_2^*(z_i),z_i)=c+m_1^*+\Delta+f(m_1^*)-(1+z_i)f(m_2^*(z_i))$ for all $z_i<z^*$ and every firm j with strictly positive first-period production.

iii) In period 1 each consumer i purchases a new unit and m_1^* units of maintenance.

iv) In period 2 each consumer i for whom $z_i>z^*$ purchases a new unit and m_1^* units of maintenance from firm j_i.

v) In period 2 each consumer i for whom $z_i<z^*$ consumes his used unit and purchases $m_2^*(z_i)$ units of maintenance from firm j_i (each consumer i for whom $z_i=z^*$ is characterized either by the behavior described in iv) or that described in v)).

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

Proposition 2 tells us that, when monopolizing the maintenance market is an option, each durable goods producer monopolizes the maintenance market for its own product and this in turn avoids the inefficiency identified in Proposition 1.[10] There are two steps to the argument. The first is to note that, by optimally setting the second-period price for a new unit and the price schedule for maintenance, a firm that monopolizes the maintenance market for its own product can extract all the available second-period surplus from consumers who purchased new units from the firm in the first period (there is surplus because of the presence of the switching cost and because some used units require little maintenance). As shown in condition i), for repeat purchasers the firm does this by charging Δ more for a new unit and the first-best level of maintenance than alternative suppliers would charge for these items. As shown in condition ii), for a consumer who maintains his used unit, the firm increases the price for the used unit's first-best level of maintenance so that the consumer is indifferent between maintaining his used unit by purchasing this first-best level of maintenance from the firm and purchasing a new unit and a new unit's first-best level of maintenance from alternative suppliers.

The second step of the argument is to note that this first result means that monopolizing the maintenance market avoids the inefficiency identified in Proposition 1, which, in turn, means that firms monopolize the maintenance markets for their own products and there is a corresponding increase in both

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[10] If we allowed durable goods producers to lease as well as sell new units of output, then in equilibrium each firm would monopolize the maintenance market for its own product and either sell or lease its output.

consumer and social welfare. That is, since a firm that monopolizes the maintenance market for its own product is able to extract all the available surplus from second-period consumers who purchased new units from the firm in the first period, the firm maximizes second-period profits by inducing these consumers to make efficient second-period choices. But since competition means that over the two periods every durable goods producer earns zero expected profits, avoiding inefficient second-period decisions must improve consumer welfare. The end result is that in equilibrium consumers purchase from firms that monopolize their own maintenance markets because purchasing from such a firm results in higher consumer and social welfare.

An interesting extension of the model is to consider what happens when the restriction v_L-Δ-f(0)>0 is not satisfied. For example, suppose v_L=0.[11] Then there would be a second distortion associated with competitive maintenance that would also be eliminated when durable goods producers monopolize the maintenance markets for their own products. Specifically, consider first the benchmark case in which Δ=0 and the maintenance market is competitive. If v_L=0, then there will be a critical value for v_i, call it v*, such that in period 1 consumer i purchases a durable unit if v_i>v* and does not if v_i<v*. Now consider what happens when Δ>0 and and the maintenance market is competitive. In addition to the distortion concerning the maintenance decision, there will also be a distortion concerning which consumers purchase the durable product in the first period. That is, there will again be a critical value for v, call it v′, such that in period 1 consumer i purchases a durable unit if v_i>v′ and does not if v_i< v′. But there is a distortion because v′>v* (this result is shown formally at the end of the proof of Proposition 1 in the Appendix). The logic is that for any consumer i the distortion concerning the maintenance decision lowers the consumer's net benefit of purchasing a new durable unit in the first period, so some consumers who purchase new durable units in the first period in the benchmark case choose not to purchase in the first period given switching costs and competitive maintenance.

But what is of particular interest is that in this case allowing durable goods producers to monopolize the maintenance markets for their own products eliminates both the distortion concerning the maintenance decision and the distortion concerning the participation decision. The logic is as follows.

[11] In the discussion that follows we make what we believe to be the realistic assumption that every consumer who purchases a durable unit in the first period chooses to either maintain the unit in the second period or replace it with a new durable unit. From a modeling perspective this will be the case if, as was true in the *Kodak* case, there are large durable sunk investments associated with consuming the durable product (see footnote 3 for a related discussion concerning Kodak).

As discussed above, the distortion concerning who purchases in the first period is a direct result of the distortion concerning the maintenance decision. So when firms monopolize the maintenance markets for their own products and in this way eliminate the distortion concerning the maintenance decision, they also in turn eliminate the distortion concerning who purchases a durable unit in the first period.[12]

Another interesting extension concerns the choice of maintenance market monopolization in real world cases. An important question that arises in many of the relevant cases is why does the firm monopolize the maintenance market by refusing to sell spare parts to alternative maintenance suppliers rather than just increase the price for spare parts? A variant of the model analyzed above can be used to answer this question. In this variant, maintenance consists of service and spare parts, where the demand for these products is stochastic. What happens in equilibrium is that a firm is able to fully extract consumer surplus in the second period when it monopolizes the maintenance market but not when it increases the price for spare parts, and this means efficient maintenance and replacement decisions given maintenance market monopolization but not for monopoly pricing of spare parts. The reason is that extracting all the consumer surplus in the second period requires a price function for maintenance that cannot be achieved by simply having the price function for maintenance be of the form $c_S+n_PP_P$, where c_S is the cost of providing service, n_P is the number of parts required, and P_P is the price the durable goods producer charges for parts. In other words, when durable goods producers can choose between the two behaviors, maintenance market monopolization results in higher consumer and social welfare and is therefore preferred by consumers.[13]

III. DURABLE GOODS COMPETITION AND MONOPOLY UPGRADES

In this section we investigate a model related to the model of the previous section but now we

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[12] Another aspect of this result is that competition in the new-unit market in the first period reduces the first-period price so that over the two periods the expected payments made by any consumer who purchases a new durable unit in the first period just covers the expected costs of production and maintenance. And this in combination with the elimination of the maintenance distortion means there is no distortion concerning the participation decision. Further, note that this part of the argument depends on consumers being forward looking and correctly anticipating in the first period what second-period prices will be. So, in contrast to what was true in the main analysis (see footnote 7), here if consumers in the first period do not correctly anticipate second-period prices, the likely result would be that maintenance market monopolization will not lead to fully efficient behavior. We would like to thank one of the referees for pointing this out to us.

[13] A different variant of the model that incorporates unobservable quality can explain why, if long-term contracting is possible, durable goods producers choose to monopolize the maintenance markets for their own products rather than sign long-term contracts in the first period that specify the second-period price for new units of output.

extend it to include product improvements and product upgrades rather than maintenance expenditures. To focus attention on the key points, we suppress the stochastic element of the previous model, but allow a richer specification for consumer heterogeneity, i.e., consumers vary in terms of the increased utility associated with purchasing a new unit in the second period rather than consuming an upgraded used unit. The main result of the analysis is that some firms (but not necessarily all) choose to monopolize the upgrade market when given the opportunity, where there are now two factors driving this choice. First, similar to the previous analysis, monopolization eliminates a distortion concerning the upgrade versus replacement decision. Second, a new factor here is that monopolization eliminates the cross-subsidization of consumers who upgrade by consumers who purchase new units in the second period, where by cross-subsidization we mean that in the absence of monopolization there is a premium paid by consumers who purchase new units in period 2 that reduces the new-unit price for all consumers in period 1.

A) The Model

The model is similar to the model analyzed in the previous section. Consider a two-period setting in which there are two perfectly competitive industries, where here one produces a durable good while the other produces a complementary product. One difference here is that durable goods firms produce higher quality units in the second period than in the first, i.e., there are product improvements. A second difference is that now the complementary product is upgrades rather than maintenance, where an upgrade purchased in the second period improves the functionality of a used unit. As before, each durable goods producer has a constant marginal cost of producing a new unit equal to c and no fixed costs. Also, as before, a used unit that is not used for consumption has a scrap value equal to zero.

Upgrades for used durable units produced by firm j can be supplied either by competitive upgrade producers or by firm j itself, where each type of firm has no fixed costs of producing an upgrade and a constant marginal cost c_U, $c_U<c$. Note, since the upgrade industry is perfectly competitive, each competitive upgrade producer sells upgrades at a price equal to c_U. We allow for two possibilities concerning the upgrade market. We first assume durable goods producers cannot stop consumers from purchasing upgrades from competitive upgrade producers. We then assume each durable goods producer can stop this behavior through, for example, product design and in this way can monopolize the upgrade market for its own product.

On the demand side, we again assume a continuum of nonatomic consumers whose total mass is normalized to one. We also again assume consumer switching costs and that consumers are heterogeneous in terms of their basic valuations for the durable product. In the first period each consumer i receives a gross benefit v_i from consuming a new unit produced by any durable goods manufacturer, where as before the distribution of v_is in the population is described by a density function g(.), g(v)>0 for all $v \in [v_L, v_H]$ and g(v)=0 for all v outside of this interval. We also assume $v_L > c$, where this assumption ensures that all consumers purchase a new durable unit in the first period. Note, as before, 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 the second period is as follows. Let Δ again denote the size of the switching cost, j_i again be the producer of the durable unit consumed by individual i in the first period, while x_i is now the disutility that individual i receives from the reduced functionality associated with consuming an upgraded used unit in the second period rather than a new unit. There are five possibilities. First, in the second period each consumer i receives a gross benefit equal to $(1+\alpha)v_i$, $\alpha > 0$, from consuming a new durable unit produced by firm j_i. As is made clear below, α captures the extra second-period gross benefit associated with consuming a new unit rather than a used unit that has not been ungraded. Second, he receives a gross benefit equal to $(1+\alpha)v_i - \Delta$ from consuming a new durable unit produced by a firm other than j_i. Third, if consumer i did not consume a new unit in the first period, then he receives a gross benefit equal to $(1+\alpha)v_i$ from consuming a new durable unit produced by any manufacturer. Note, we also assume $v_L\alpha - \Delta > c$ which ensures that in equilibrium all consumers either upgrade or purchase a new unit in the second period.

The fourth and fifth cases concern individuals who consume the used durable units they purchased as new in the first period. Fourth, if individual i consumes his used unit and does not upgrade, then he receives a gross benefit equal to v_i. Fifth, if individual i consumes his used unit and upgrades, then he receives a gross benefit equal to $(1+\alpha)v_i - x_i$, where the distribution of x_is in the population is independent of the distribution of v_is and is described by a density function h(.), h(x)>0 for all $x \in [x_L, x_H]$ and h(x)=0 for all x outside of this interval. We also assume $x_L < c - c_U < x_H$ and that each individual i's value for x_i is privately known by individual i. Note, the assumption $x_L < c - c_U < x_H$ means that in the second period it is efficient for some consumers to upgrade and others to purchase new units.[14] Finally, as before, all firms and all consumers are risk neutral and have a discount factor β, $0<\beta<1$.

The timing of the model is as follows. The first period consists of three stages. First, when monopolizing the upgrade market is an option, each durable goods producer decides whether to allow competition in that market or monopolize the upgrade market for its own product. Second, each durable goods producer chooses a new-unit price. Third, each consumer makes his purchase decisions. The second period consists of two stages. First, each durable goods producer chooses a new-unit price and each durable goods producer that monopolizes the upgrade market for its own product chooses an upgrade price.[15] Second, each consumer makes his purchase decisions.

B) Analysis

As in the previous model, we start by discussing a benchmark analysis in which there are no consumer switching costs, i.e., $\Delta=0$. Suppose $\Delta=0$ and the upgrade market is competitive. Because there are no switching costs, the price for a new durable unit is c in each period, while the competitive upgrade market means that the second-period upgrade price equals c_U. Let $x^*=c-c_U$. What happens is that in the first period every consumer purchases a new durable unit, while in the second consumers for whom $x_i>x^*$ purchase new units while those for whom $x_i\leq x^*$ purchase upgrades.[16] Let U_i^* denote the present discounted value of consumer i's net benefits over the two periods in this case (as in the previous model, since both markets are perfectly competitive the expected profitability of a firm in each market equals zero), while $\sum U_i^*$ is the present discounted value of net benefits summed over all the consumers in this case. Note further, because both markets are competitive and there are no switching costs, x^* represents the first-best critical value for x and $\sum U_i^*$ measures social welfare in addition to consumer welfare.

We now assume consumer switching costs and consider what happens when the upgrade market is competitive. Below P_{jt}^C denotes durable goods producer j's price for a new unit of output in period t in

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[14] Similar to what we assumed in the previous model (see footnote 5), we assume h(.) is such that when the upgrade market is competitive there is a unique second-period price for new durable units that maximizes second-period profits for a firm that sells a strictly positive number of new durable units in the first period.

[15] As was true in the previous model (see footnote 6), for the analysis of the second-period pricing game we assume there is free entry into the market for new durable units in the second period as well as the first.

[16] Throughout the analysis we assume that a consumer who receives the same second-period net benefit from upgrading his used unit as from replacing it prefers to upgrade it (see footnote 8 for a similar assumption in the previous model). This assumption simplifies the statements of the propositions.

this case, U_i^C denotes the present discounted value of the net benefits received by consumer i in this case, and $\sum U_i^C$ is the present discounted value of net benefits summed over all the consumers in this case. Note that in this model, in contrast to the previous one, we focus on the sum of net benefits across consumers because the presence of consumer switching costs hurts some consumers but helps others.

Proposition 3: Suppose the upgrade market is competitive and there are consumer switching costs. There exist critical values x' and x'', $x'>x''>x^*$, such that i) through v) describe the unique equilibrium.[17]

i) $P_{j1}^C<c$ and $P_{j2}^C>c$ for every durable goods producer j with strictly positive production in the first period.

ii) In period 1 each consumer i purchases a new durable unit.

iii) In period 2 each consumer i for whom $x_i>x'$ replaces his used unit with a new unit purchased from firm j_i.

iv) In period 2 each consumer i for whom $x_i\leq x'$ purchases an upgrade at price c_U.

v) $U_i^C<(>)U_i^*$ for all i for whom $x_i>(<)x''$ ($U_i^C=U_i^*$ if $x_i=x''$) and $\sum U_i^C<\sum U_i^*$.

Proposition 3 tells us there is an inefficiency when the upgrade market is competitive and there are consumer switching costs. Specifically, $x'>x^*$ tells us some consumers upgrade their used units when the units would be more efficiently replaced. The logic here is similar to the logic for the similar result in the previous model. Because of switching costs, a durable goods producer with positive first-period production has market power in selling new units in the second period to its first-period buyers. As a result, in the second period consumers face a competitive price for upgrades and an above competitive price for purchasing a new unit from the firm it purchased a new unit from in the first period. The end result is that too many consumers choose to upgrade rather than purchase new units in the second period.

There is one interesting difference between the above result concerning competition in upgrades and switching costs and the result of the previous section concerning a competitive maintenance market and switching costs. In the previous section the inefficiency caused by the switching costs hurt every consumer. In contrast, here switching costs help some consumers and hurt others, although as in the

[17] We restrict the analysis in Propositions 3 and 4 to equilibria in which consumers treat firms that employ the same strategy in an equivalent way. What this means for Proposition 3 is that, if a consumer purchases in the first period from a firm offering a new unit at the lowest price and there are multiple firms tied at the lowest price, the consumer has the same probability of purchasing from each of the firms.

previous model aggregate consumer and social welfare fall. In particular, the consumers who purchase new durable units in the second period are hurt by the switching costs, but of those who purchase upgrades some are hurt but others are helped.

The logic for this result is as follows. The presence of switching costs causes the first-period new-unit price to fall because a first-period sale increases expected profits in the second period. Since this price falls while the second-period price for an upgrade is unchanged, consumers who upgrade in both the benchmark analysis and here are made better off by the introduction of switching costs. However, those who purchase new units in the second period in both cases are hurt by the introduction of switching costs since switching costs cause the second-period price paid by these consumers to increase more than the first-period price falls. Finally, of the consumers who purchase new units in the second period in the benchmark analysis and upgrades here, the introduction of switching costs helps some but hurts others. The reason is that there are opposing forces – given switching costs these consumers on the one hand purchase the "wrong" good, but on the other they benefit in the first period as firms compete away profits from the second-period sales of new units.

We now consider what happens when each firm has the option of monopolizing the upgrade market for its own product. Below P_{jt}^M denotes producer j's new-unit price in period t in this case, U_i^M denotes the present discounted value of consumer i's net benefits over the two periods in this case, and $\sum U_i^M$ denotes the present discounted value of net benefits summed over all the consumers in this case.

<u>Proposition 4</u>: Suppose each durable goods producer has the option of monopolizing the upgrade market for its own product and there are consumer switching costs. Then every equilibrium is characterized by i) through v), where in each equilibrium at least two durable goods producers choose to monopolize the upgrade markets for their own products.[18]

i) $P_{j1}^M=c-\beta\Delta$ and $P_{j2}^M=c+\Delta$ for every firm j with strictly positive production in the first period that monopolizes the upgrade market for its own product.

ii) $P_{j1}^M=c$ for every firm j with strictly positive production in the first period that does not monopolize the upgrade market for its own product.

iii) In period 1 each consumer i for whom $x_i>x^*$ purchases a new durable unit from a firm that

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[18] There are multiple equilibria because consumers for whom $x_i\leq x^*$ can purchase either from firms that monopolize the upgrade market or firms that do not.

monopolizes the upgrade market for its own product, while in the second period it purchases a new unit from the same firm.

iv) In period 1 each consumer i for whom $x_i \leq x^*$ purchases a new durable unit either from a firm that monopolizes the upgrade market or one that does not, while in the second period it purchases an upgrade.

v) $U_i^M = U_i^*$ for all i and $\sum U_i^M = \sum U_i^* > \sum U_i^C$.

Proposition 4 tells us that, when monopolizing the upgrade market is an option, then some (at least two) durable goods producers monopolize the upgrade markets for their own products with the result that both the inefficiency and the cross-subsidization identified in Proposition 3 are avoided. Note that this is in contrast to the equilibrium found in Proposition 2 in which all producers chose to monopolize the maintenance markets for their own products. The logic here is as follows. Because in the earlier analysis the return to maintaining versus replacing was stochastic, given a competitive maintenance market each consumer employed an inefficient rule concerning whether to maintain or replace. Hence, to avoid inefficient decisions it was necessary for each consumer to purchase a new unit in the first period from a firm that monopolized the maintenance market for its own product.

In the model of this section, the return to upgrading rather than replacing is not stochastic, but differs across consumers. As a result, a competitive upgrade market does not mean each consumer employs an inefficient rule concerning whether to upgrade or replace, but rather specific consumers inefficiently upgrade rather than replace. As discussed above, because of this distortion and because the existence of consumers who purchase new units in the second period results in a first-period benefit to consumers who upgrade in the second, given a competitive upgrade market and switching costs all the consumers who replace and some who upgrade are hurt by the switching costs.

Given this, consider what happens when monopolizing the upgrade market is an option. By purchasing from a firm that monopolizes the upgrade market a consumer who plans on purchasing a new unit in the second period can avoid subsidizing consumers who purchase upgrades. The reason is that, given the firm monopolizes the upgrade market, every consumer who purchases from the firm in the first period pays a premium to the firm in the second. As a result, all the consumers above who are hurt by the presence of switching costs, i.e., consumers for whom $x_i > x''$, purchase from firms that monopolize the upgrade market because this avoids the cross-subsidization. Further, consumers who inefficiently upgraded in the competitive case with switching costs but were better off, i.e., consumers for whom $x^* < x_i \leq x''$, also purchase from firms that monopolize the upgrade market in order to avoid subsidizing consumers for whom $x_i \leq x^*$. Finally, since they are not trying to avoid cross-subsidization, consumers for whom $x_i \leq x^*$ can purchase from firms that do not monopolize the upgrade market.[19]

IV. AN ANALYSIS OF REMANUFACTURING

In this section we consider durable goods producers that sell remanufactured parts to the consumers of their products. In particular, our focus is on the practice of original producers of offering a discount or what is called the "core charge" to consumers who return the broken or worn out part to the original producer, where the core charge is frequently significantly above the scrap price of the part. This practice has drawn antitrust complaints because a high core charge makes it difficult for rival remanufacturers to profitably obtain the worn out parts needed for the remanufacturing process. In other words, the complaint is that a high core charge is a way for a durable goods producer to monopolize the market for remanufactured parts used to repair its own products. We construct a model in which this is indeed the case, but show that in our model the practice increases rather than decreases social welfare.

A) The Model

Consider a three-period model characterized by a durable goods monopolist, a perfectly competitive maintenance industry, and a perfectly competitive remanufacturing industry, where all consumers and firms have a discount factor β, $0<\beta<1$. The monopolist has a constant marginal cost of production equal to c, $c>0$, and no fixed costs, where a unit lasts three periods. A unit of the monopolist's output contains a part that requires no maintenance when new, but has a probability p_j of becoming worn out when it is j periods old, $p_2>p_1$. A worn out part can either be maintained or replaced, where replacement can be with either a new part or a remanufactured part. By a remanufactured part we mean a worn out part that has been reconditioned so that it is a perfect substitute for a new part. Note that we

[19] One question that arises is what happens when there are two aftermarket products such as maintenance and upgrades. If both are substitutable with purchasing a replacement unit, then given a similar set-up to those considered in Sections II and III durable goods producers would want to monopolize both aftermarkets and such monopolization would improve welfare. On the other hand, suppose only one aftermarket product was substitutable with purchasing a replacement unit but the two aftermarket products were substitutable with each other, then again durable goods producers would want to monopolize both aftermarkets and such monopolization would improve welfare.

could instead assume that a remanufactured part is not as good as a new part but this would not change the qualitative nature of the results.

The durable goods monopolist is the sole producer of new parts, where the firm's constant marginal cost of producing a new part equals c_p, $c_p<<c$ (think of a truck as being the unit and a carburetor as being the part). We assume there is a competitive remanufacturing industry and that the monopolist can also remanufacture worn out parts. The way that remanufacturing works is that in the second period a consumer with a worn out part has the option of selling his worn out part to either a competitive remanufacturer or the monopolist, where the price the monopolist offers for the part is called the core charge. In the third period a firm that purchased a worn out part in the second period remanufactures the part and sells the remanufactured part to a consumer who needs to replace a worn out part. Competitive remanufacturers remanufacture worn out parts at a per unit cost c_r, $c_r<c_p$, while due to economies of scope between the production of new parts and the remanufacture of worn out parts the monopolist's per unit cost of remanufacturing is c_r', $c_r'<c_r$. A worn out part that is replaced but is not remanufactured has a scrap value equal to y, $y<\beta(c_p-c_r)$. The assumption $y<\beta(c_p-c_r)$ ensures that it is efficient for second-period worn out parts to be remanufactured rather than scrapped.

Instead of replacing a worn out part, another option is to maintain the part. In particular, a worn out part that receives maintenance of level M is a perfect substitute for a new part and a remanufactured part. Further, the original durable goods producer does not sell maintenance for worn out parts but rather there is a perfectly competitive maintenance industry that provides maintenance for worn out parts (again, think of the unit as being a truck and the part as being a carburetor). Each firm in this industry has no fixed costs of supplying maintenance while the variable costs of supplying M units of maintenance equal M. This means that firms in the competitive maintenance industry sell M units of maintenance at a price equal to M. We also assume $0<c_p-y<M$. This assumption states that it is efficient for worn out parts to be replaced rather than maintained.

On the demand side, we again assume a continuum of nonatomic consumers whose total mass is normalized to one. To be specific, in each period each consumer i receives a gross benefit equal to v, $v>c$, from consuming a durable unit that contains either a new part, a new remanufactured part, a used part that is not worn out, or a worn out part that has received maintenance of level M. Further, a consumer receives a gross benefit of zero from consuming a unit that contains either no part or a worn out part that has not received the required level of maintenance.

The timing is as follows. The first period consists of two stages. First, the monopolist announces a price for new units. Second, each consumer then chooses whether or not to purchase a new unit. The second period also consists of two stages. First, the monopolist announces a new-unit price, a new-part price, and the core charge. At the same time each competitive remanufacturer announces a price at which it will purchase worn out parts. Second, consumers then decide what to purchase, sell, scrap, and maintain. The third period consists of the following two stages. First, the monopolist announces a new-unit price and a new-part price (because it is the last period all worn out parts are scrapped). At the same time firms choose the prices at which they will sell remanufactured parts. Second, consumers then decide what to purchase, scrap, and maintain.

B) Analysis

The analysis in this subsection proceeds in three steps. First, we discuss the results of a benchmark analysis in which the durable goods monopolist does not remanufacture worn out parts. Second, we consider what happens when the monopolist does remanufacture worn out parts and is the low-cost remanufacturer. Third, we briefly discuss what happens when the durable goods monopolist is not the low-cost remanufacturer.

The following describes the equilibrium when the durable goods monopolist does not remanufacture worn out parts. First, all consumers purchase a new unit in the first period. Second, in the second period the monopolist charges $M+P'$ for a new part, every consumer with a worn out part purchases a new part from the monopolist, and every such consumer sells the worn out part to a competitive remanufacturer at a price P', where $P'=\beta(M+y-c_r)$. Note, since $M>c_p-y$ and $\beta(c_p-c_r)>y$, we have that $P'>y$. Third, in the third period the monopolist charges $M+y$ for a new part while remanufacturers charge $M+y$ for remanufactured parts, and every consumer with a worn out part purchases either a new part from the monopolist or a remanufactured part from a competitive remanufacturer. Since this is the last period each such consumer scraps his worn out part.

The logic here is as follows. Since it is cheaper for the monopolist to produce a new part than for a worn out part to be maintained, in the second period the monopolist charges the highest price at which consumers replace rather than maintain worn out parts. This means a second-period new part price equal to $M+P'$. In the third period a worn out part can be replaced with either a new part or a remanufactured part, where the two types of parts are perfect substitutes. Further, since worn out parts are scrapped rather than sold to remanufacturers in the third period, the same logic yields that in the third period all worn out parts are replaced by one of these two types of parts where each type sells for M+y. Finally, the price at which remanufacturers purchase worn out parts in the second period is determined by competition among the remanufacturers. Since competition means remanufacturing profits equal zero, we have $P'+\beta c_r=\beta(M+y)$ or $P'=\beta(M+y-c_r)>y$, i.e., competition drives the price at which remanufacturers purchase worn out parts in the second period above the scrap price of the part.

We now assume the monopolist can remanufacture worn out parts and is the low-cost remanufacturer. Let P_t^p denote the monopolist's period-t new-part price, P_3^r the monopolist's price for a remanufactured part in period 3, and P' now denotes the core charge, i.e., the period-2 discount offered by the monopolist for a worn out part. Also, π^* denotes monopoly profitability in the benchmark case, π^m denotes monopoly profitability here, EU* denotes a representative consumer's expected net benefits in the benchmark case, and EU^m denotes expected net benefits of a representative consumer here.

Proposition 5: Suppose the durable goods monopolist is the low-cost remanufacturer. Then i)-v) characterize every equilibrium.[20]

i) Each consumer purchases a new unit in the first period and there are no purchases of new units in the second and third periods.

ii) Every consumer with a worn out part in the second period replaces it with a new part and sells the worn out part to the monopolist.

iii) Every consumer with a worn out part in the third period replaces it with a new part or a remanufactured part and scraps the worn out part.

iv) $P_2^p=M+P'$, $P_3^p=P_3^r=M+y$, and $P'\geq\beta(M+y-c_r)>y$.

v) $\pi^m>\pi^*$ and $EU^m=EU^*=0$.

Proposition 5 tells us that when the monopolist is the low-cost remanufacturer then the outcome is similar to the benchmark analysis except the monopolist is the sole remanufacturer. That is, the durable goods monopolist offers a core charge sufficiently high that it monopolizes the remanufacturing market,

[20] There are multiple equilibria because, as indicated in iv), P' is not uniquely defined.

where consistent with recent antitrust complaints the core charge is above the scrap price of the part.[21] The key point here, however, is that, although the high core charge is used to to monopolize the remanufacturing market, the behavior increases rather than decreases social welfare. In other words, comparing what happens in Proposition 5 with the benchmark equilibrium yields that monopolizing the remanufacturing market leaves consumer welfare unchanged and increases monopoly profitability (each remanufacturer earns zero profits in both cases), where the increase in monopoly profitability is due to worn out parts being remanufactured here in a lower cost fashion than in the benchmark analysis.

We now briefly discuss what happens when the durable goods monopolist is the high-cost rather than the low-cost remanufacturer, i.e., $c_r' > c_r$. In this case the durable goods monopolist would not monopolize the remanufacturing market and the unique equilibrium is the benchmark equilibrium described above. This result reinforces the discussion above concerning why the durable goods monopolist monopolizes the remanufacturing market in Proposition 5. The firm does not monopolize the remanufacturing market because there is a return to monopolization in the absence of a cost advantage. Rather, the only return associated with monopolization is the cost savings associated with being the low-cost remanufacturer which explains why it monopolizes the remanufacturing market in Proposition 5, but stays out of that market when it is the high-cost remanufacturer.[22]

V. ALTERNATIVE THEORIES

In Sections II, III, and IV we presented three models in which aftermarket monopolization served to increase social welfare. In this section we discuss the major alternative explanations for aftermarket monopolization.

Because of interest in the *Kodak* decision, most of the previous literature on this topic focuses on why a durable goods producer would monopolize the maintenance market for its own product, where, in contrast to the analysis of Section II, in most of these analyses the practice reduces rather than increases

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[21] In our model, in the second period no worn out parts are actually scrapped in equilibrium, so the second-period core charge is higher than a scrap price that is never paid in the second period. It would be simple, however, to complicate the model so only a fraction of worn out parts are such that remanufacturing is possible. In this case the second-period core charge would again exceed the scrap price, where now the second period would be such that some worn out parts are scrapped.

[22] If $c_r' = c_r$, then the durable goods monopolist is indifferent between monopolizing and not monopolizing the remanufacturing market, and whether or not it monopolizes the remanufacturing market has no effect on either consumer welfare, social welfare, or monopoly profitability.

social welfare. We start by discussing three closely related theories based on consumer lock-in.[23] We then discuss the price discrimination explanation for the phenomenon, Shapiro's reputation argument, and a few alternative efficiency explanations. More in depth discussions of alternative theories appear in Shapiro (1993), Chen, Ross, and Stanbury (1998), and Carlton (2001).

One theory that has been put forth is the "surprise" theory. The key elements here are that consumers are locked-in once they purchase a new unit of output from a durable goods producer, and consumers expect the maintenance market to be competitive. What happens is that the producer exploits the consumers' locked-in positions by first stopping other firms from selling maintenance and then raising the price of maintenance. In this theory consumers are hurt by the monopolization both because the surprise causes the equivalent of a lump sum transfer between the consumers and the firm, and because monopoly pricing of maintenance results in a deadweight loss. The deadweight loss here has two components. Consumers of used units purchase less maintenance than is efficient and consumers replace used units too quickly.

A closely related explanation is the "costly information" theory. This theory is similar to the surprise theory in that the durable goods producer exploits the consumers' locked-in positions by monopolizing the maintenance market and then raising the maintenance price. The difference is that this is not a surprise to consumers but rather consumers simply ignore the cost of maintenance in their decisions to purchase new units. In contrast to the surprise theory, there is no transfer between consumers and the firm because competitive firms reduce the new-unit price so that they receive zero profits in equilibrium.[24] However, similar to the surprise theory, the monopoly price of maintenance results in a deadweight loss. Also, because consumers ignore the price of maintenance, the reduction of the new-unit price below cost also results in a deadweight loss.

The third theory that depends on consumer lock-in is the "lack of commitment" theory developed in Borenstein, Mackie-Mason, and Netz (1995,2000). In contrast to the above two theories, here

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[23] Consumer lock-in refers to a situation in which after aftermarket monopolization a durable goods producer can raise the aftermarket price above the competitive level without causing consumers of the firm's durable product to switch to another producer. A setting can be characterized by consumer lock-in in the absence of switching costs in the sense that a durable goods producer can have the ability to raise the aftermarket price soon after a new durable unit is purchased even if consumers are indifferent across durable goods producers when the durable unit is replaced, but switching costs will typically increase the degree of lock-in. For a discussion see Borenstein, Mackie-Mason, and Netz (2000).

[24] 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 the firm.

consumers correctly anticipate when a durable goods producer will monopolize the maintenance market and pay less for a new unit when they anticipate monopolization. In this argument durable goods producers want to commit to allowing competition in the maintenance market, but monopolization occurs because of an inability to commit. In this theory the only cost of the practice is the deadweight loss due to the monopoly pricing of maintenance. Note, however, that both Shapiro (1995) and Chen and Ross (1998) provide analyses that suggest this deadweight loss is likely to be small.

Note that these theories have a weakness concerning applicability to many of the relevant real world cases. That is, as discussed earlier, in the typical case the durable goods producer monopolized 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 provides a clear explanation for this behavior. In each case it seems the durable goods producer could have achieved its goal by raising the spare part price rather than monopolizing the maintenance market by refusing to sell spare parts to alternative maintenance suppliers.[25]

Another explanation for maintenance market monopoly is that the practice helps a firm more effectively price discriminate (see Klein (1993) and Chen and Ross (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. 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 ex ante would monopolize the maintenance market.[26]

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[25] One way of extending each of these theories so that monopolizing the maintenance market is preferred to raising the price of spare parts is to assume that service and the replacement of defective parts are substitutes in the maintenance production function rather than being used in fixed proportions. Then, 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, monopolization would be more profitable because it would avoid this inefficient substitution. Note that, in contrast to the public policy recommendation that follows from the simple version of each theory, this extension suggests the government should allow durable goods producers to monopolize the maintenance markets for their own products. The reason is that there will be a monopoly price for maintenance whether or not monopolization is allowed, and thus allowing monopolization is superior because it avoids the inefficient substitution of service for spare parts.

[26] Klein argues that in the real world there is significant price discrimination even in industries that are quite competitive, and thus that the price discrimination argument should not be ruled out as a possible explanation for maintenance market monopolization in such industries. Also, another explanation for why a durable goods

The next argument we consider is that of Shapiro (1995). Shapiro considers a setting in which a durable goods producer is in the market for multiple periods and the firm's behavior in one period affects consumer expectations in later periods. Shapiro argues that if incentives to maintain a positive reputation are sufficiently strong, then a durable goods producer that monopolizes the maintenance market for its own product will charge a competitive price for maintenance. The logic is that, even though short-run profits are higher if the firm increases the maintenance price, due to effects on long-run profits the firm chooses the competitive price. Note that Shapiro's argument does not in fact provide an explanation for why a firm would monopolize the maintenance market in the first place. That is, since in his argument a firm that monopolizes the maintenance market charges the competitive price, the firm's profitability is no higher than if it had allowed maintenance to be provided by the competitive sellers.[27]

Finally, a few authors have previously put forth efficiency explanations for aftermarket monopolization, although the specifics of the arguments are different than the arguments put forth here. For example, Chen and Ross (1999) focus on a competitive setting in which maintenance for a limited time period is bundled with the sale of new durable units and consumers vary in how heavily they use the durable product. They show that aftermarket monopolization both stops consumer cross-subsidization and improves efficiency by moving maintenance choices toward efficient levels. Another example is Elzinga and Mills (2001) which considers a durable goods oligopoly setting characterized by increasing returns to scale in the production of new durable units. That paper shows that Ramsey optimal pricing requires both new durable units and maintenance to be priced above marginal cost, and this can only be achieved by having durable goods producers monopolize the aftermarkets for their own products.

In summary, there are a number of alternative explanations for why a durable goods producer would monopolize a related aftermarket, where most of the focus has been on the market for maintenance. However, only a few of the previous explanations were focused on possible efficiencies associated with the practice. The contribution of our paper is to provide a number of additional settings in which the

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producer with significant market power would monopolize the maintenance market for its own product has been put forth in Hendel and Lizzeri (1999). In that argument a monopolist in the market for new units monopolizes the maintenance market in order to control the speed of product quality deterioration. The argument is related to analyses concerning price discrimination and imperfect substitutability between new and used units found in Waldman (1996,1997) and Fudenberg and Tirole (1998).

[27] Shapiro's argument suggests that if we extended our analysis of Sections II and III to infinite-period settings there may be an equilibrium in which inefficiencies are avoided even in the absence of aftermarket monopolization. However, modeling reputation formation in perfectly competitive settings is difficult.

practice serves to improve efficiency. And by doing so we show that aftermarket monopolization that improves welfare may be much more common than the previous literature suggests.

VI. CONCLUSION

Most of the recent attention paid to aftermarket behavior has started from the premise that a competitive aftermarket is an efficient aftermarket, and thus behaviors that limit competition in aftermarkets typically reduce social welfare. Our basic point is that this starting premise is wrong in a variety of settings. We first showed that, in a setting characterized by competitive durable goods producers and switching costs, aftermarket monopolization of the maintenance market serves to eliminate the inefficient substitution of maintenance for the replacement of new units. We then showed a similar result in a setting where the aftermarket product is durable good upgrades rather than maintenance. In our final analysis we showed that the common practice of monopolizing the market for remanufactured parts by setting a high core charge is the efficient outcome when there are economies of scope between the production of new parts and the remanufacturing of worn out parts.

Since the 1992 *Kodak* decision, significant attention has been paid to whether durable goods producers should be allowed to monopolize aftermarkets associated with their own products. Based on previous theoretical explanations for aftermarket monopolization which we discussed in Section V, a number of authors have argued that prohibiting such behavior may enhance social welfare (see, e.g., Salop (2000)). Based on the results of our analysis which suggests that aftermarket monopolization that improves welfare may be more common than previously thought, we would argue that a less interventionist policy which puts significant weight on possible efficiencies is optimal.[28]

There are a number of direction in which the analysis in this paper could be extended, where there are two that we believe are of particular interest. First, in our first two analyses we assume that the durable goods market is perfectly competitive while in the real world durable goods markets characterized by aftermarket monopolization there is typically at least some market power. So one interesting direction for further analysis is to consider settings similar to those considered in Sections II and III but where durable goods production is either oligopolistic or monopolistically competitive. Our conjecture is that

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[28] For a general discussion of our views of optimal antitrust policy for tying behavior see Carlton and Waldman (2005) and Carlton, Greenlee, and Waldman (2008). For another interesting perspective that focuses more on the limits of the efficiency-type arguments that we focus on see Farrell and Weiser (2003).

such an analysis would yield results similar to what we found in Sections II and III as long as the degree of market power is limited. But at this point this is just a conjecture and formal analysis is worthwhile.

Second, there are now a number of formal theoretical models where aftermarket monopolization reduces welfare and also a number of models where aftermarket monopolization serves to improve welfare (and also some models where the practice has an ambiguous effect on welfare). Careful empirical analysis focused on identifying which type of setting real world cases most closely resemble is clearly worthwhile at this point.

APPENDIX

Proof of Proposition 1 and Related Results: We start by proving Proposition 1. Consider firm j's second-period pricing decision where firm j sold a strictly positive number of new units in the first period. If $P_{j2}^C \leq c$, then the firm's second-period profits are less than or equal to zero. Similarly, if $P_{j2}^C > c+\Delta$, then the firm's second-period profits equal zero. This follows given there is free entry into the market for new durable units in both periods (see footnote 6) since this means other firms are willing to sell new units in the second period at a price equal to c. If $c < P_{j2}^C \leq c+\Delta$, then a consumer who purchases a new unit from firm j in the first period purchases a new unit from firm j in the second period if he purchases a new unit (to be precise, if $P_{j2}^C = c+\Delta$ then the consumer is indifferent between purchasing a new unit from firm j and purchasing a new unit from a firm that sells new units at price c). We know this because no durable goods producer would offer a new unit in the second period at a price less than c.

Given the above, since $v_L - f(0) > c$ and $h(z) > 0$ for all $z \in (0,\infty)$, all values for P_{j2}^C that satisfy $c < P_{j2}^C < c+\Delta$ yield strictly positive second-period profits. In turn, this implies that for every firm j that sold a strictly positive number of new units in the first period the unique optimal value for P_{j2}^C satisfies $c < P_{j2}^C \leq c+\Delta$ (see footnote 5). Further, given that competition causes each firm to earn zero expected profits, we have that every firm j that sells a strictly positive number of new units in the first period must have the same value for P_{j1}^C where this value satisfies $P_{j1}^C < c$. Let P_1^C denote this shared value while P_2^C denotes the shared value for P_{j2}^C. This proves i).

Now consider the second-period behavior of consumer i who purchased a new unit in the first period. In the second period this consumer has four relevant choices. First, the consumer could maintain the unit in which case he would purchase $m_2^*(z_i)$ units of maintenance (all the claims concerning maintenance expenditures follow from an analysis of the first-order conditions concerning optimal maintenance choice). In this case his second-period net benefit equals $v_i-(1+z_i)f(m_2^*(z_i))-m_2^*(z_i)$. Second, he could replace the used unit with a new unit produced by j_i in which case he would purchase

m_1* units of maintenance. In this case his second-period net benefit equals v_i-f(m_1*)-m_1*-P_2^C. Third, he could replace the unit with a new unit produced by another firm in which case he would purchase m_1* units of maintenance. In this case his second-period net benefit equals v_i-Δ-f(m_1*)-m_1*-c. Fourth, he could decide not to use the unit and not replace it. This yields a second-period net benefit equal to zero.

Since v_L-Δ-f(0)>c, we know the consumer never chooses the fourth option. Let z′ be such that (1+z′)f(m_2*(z′))+m_2*(z′)=f(m_1*)+m_1*+P_2^C. Since c<P_2^C≤c+Δ we have the following. The consumer maintains the used unit when z_i≤z′, replaces it with a new unit produced by firm j_i when z_i>z′ and P_2^C<c+Δ, and replaces it with a new unit produced by firm j_i or a new unit produced by a different firm when z_i>z′ and P_2^C=c+Δ (see footnote 8). Further, since z* satisfies (1+z*)f(m_2*(z*))+m_2*(z*)=f(m_1*) +m_1*+c, (1+z_i)f(m_2*(z_i))+m_2*(z_i) is increasing in z_i, and P_2^C>c, we have z′>z*.

Suppose there exists a firm j that sells a strictly positive number of new units in the first period, chooses P_{j2}^C=c+Δ, and has a strictly positive expected number of its first-period consumers replace their used units in the second period with new units purchased from other firms. Then the firm could increase its second-period profit by infinitesimally lowering P_{j2}^C below c+Δ since the result would be that all of the first-period consumers who purchase new units in the second period would purchase these units from firm j. This means that all of firm j's first-period consumers who purchase new units in the second period must purchase from firm j.

Since the above argument holds for every firm j that sells a strictly positive number of new units in the first period, we have the following. First, in the second period each consumer i who purchased a new unit in the first period for whom z_i≤z′ maintains his used unit and purchases m_2*(z_i) units of maintenance. Second, in the second period each consumer i who purchased a new unit in the first period for whom z_i>z′ purchases a new unit from firm j_i and purchases m_1* units of maintenance. Third, every consumer i purchases a new unit in the first period since v_L-Δ-f(0)>c, while the first-order condition concerning optimal maintenance choice yields each consumer purchases m_1* units of maintenance in the first period. This proves ii), iii), and iv).

Now consider EU_i^C. Given the above, EU_i^C is given by equation (A1).

(A1) $EU_i^C=v_i-f(m_1^*)-m_1^*-P_1^C+\beta[v_i-\int_0^{z'}[(1+z)f(m_2^*(z))+m_2^*(z)]h(z)dz-\int_{z'}^{\infty}[f(m_1^*)+m_1^*+P_2^C]h(z)dz]$

Given competition means that in equilibrium all durable goods producers earn zero expected profits, we know $P_1^C+\beta\int_{z'}^{\infty}P_2^C h(z)dz=c+\beta\int_{z'}^{\infty}ch(z)dz$. Substituting this into (A1) yields (A2).

(A2) $EU_i^C=v_i-f(m_1^*)-m_1^*-c+\beta[v_i-\int_0^{z'}[(1+z)f(m_2^*(z))+m_2^*(z)]h(z)dz-\int_{z'}^{\infty}[f(m_1^*)+m_1^*+c]h(z)dz]$

From the discussion in the text, we know EU_i* is given by (A3).

(A3) $EU_i^*=v_i-f(m_1^*)-m_1^*-c+\beta[v_i-\int_0^{z^*}[(1+z)f(m_2^*(z))+m_2^*(z)]h(z)dz-\int_{z^*}^{\infty}[f(m_1^*)+m_1^*+c]h(z)dz]$

Since by definition z* is the value for z^+ that minimizes $\int_0^{z^+}[(1+z)f(m_2^*(z))+m_2^*(z)]h(z)dz+$

$\int_{z^+}^{\infty}$ $[f(m_1*)+m_1*+c]h(z)dz$, a comparison of (A2) and (A3) yields $EU_i^C<EU_i*$ for all i.

We now formally show the claim towards the end of Section II that, if $v_L=0$, then $v'>v*$. v* is the value for v_i at which consumer i receives a zero expected net benefit from purchasing a new unit in period 1 when the maintenance market is competitive and $\Delta=0$, i.e., v* is given by equation (A4).

(A4) $v*-f(m_1*)-m_1*-c+\beta[v*-\int_0^{z*} [(1+z)f(m_2*(z))+m_2*(z)]h(z)dz-\int_{z*}^{\infty} [f(m_1*)+m_1*+c]h(z)dz]=0$

Similarly, v′ is the value for v_i at which consumer i receives a zero expected net benefit from purchasing a new unit in period 1 when the maintenance market is competitive and $\Delta>0$, i.e., v′ is given by (A5).

(A5) $v'-f(m_1*)-m_1*-P_1^C+\beta[v'-\int_0^{z'} [(1+z)f(m_2*(z))+m_2*(z)]h(z)dz-\int_{z'}^{\infty} [f(m_1*)+m_1*+P_2^C]h(z)dz]=0$

But the fact that competition yields zero profits means $P_1^C-c+\beta\int_{z'}^{\infty} (P_2^C-c)h(z)dz=0$. Adding the left hand side of this equation to the left hand side of (A5) yields equation (A6).

(A6) $v'-f(m_1*)-m_1*-c+\beta[v'-\int_0^{z'} [(1+z)f(m_2*(z))+m_2*(z)]h(z)dz-\int_{z'}^{\infty} [f(m_1*)+m_1*+c]h(z)dz]=0$

But since $z*\neq z'$ and z* is the value for z^+ that minimizes $\int_0^{z^+} [(1+z)f(m_2*(z))+m_2*(z)]h(z)dz+$ $\int_{z^+}^{\infty} [f(m_1*)+m_1*+c]h(z)dz]$, a comparison of (A4) and (A6) yields $v'>v*$.

Proof of Proposition 2: Suppose that in the first period consumer i purchases a new unit from a firm that does not monopolize the maintenance market for its own product. Then from the proof of Proposition 1 we know $EU_i^M=EU_i^C<EU_i*$.

Now consider firm j that sells a strictly positive number of new units in the first period and monopolizes the maintenance market for its own product. In terms of second-period profits, the best the firm can do in the second period is capture all of the surplus from consumers who purchased a new unit from the firm in the first period. By that we mean the following, where below consumer i now denotes a consumer who purchased a new unit from firm j in the first period.

First, if consumer i purchases a new unit from firm j in the second period, then consumer i should be indifferent between this behavior and purchasing a new unit in the second period from another firm at a price c and m_1* units of maintenance at a price m_1* since m_1* is the privately efficient number of units of maintenance to purchase for a new unit when maintenance is priced at cost. Let m^+ be the amount of maintenance the consumer purchases from firm j. We now have that $v_i-f(m^+)-P_{j2}^M-p_{j2}(m^+)=v_i-\Delta-f(m_1*)-c-m_1*$, or $P_{j2}^M+p_{j2}(m^+)=c+m_1*+\Delta+f(m_1*)-f(m^+)$. Firm j's profit in selling to this consumer as a function of m^+ thus equals $m_1*+\Delta+f(m_1*)-f(m^+)-m^+$. In turn, taking the derivative with respect to m^+ yields $m^+=m_1*$. In other words, each consumer i who purchases a new unit from firm j also buys m_1* units of maintenance from firm j and $P_{j2}^M+p_{j2}(m*)=c+m_1*+\Delta$. Further, firm j's profit in selling to this consumer equals Δ.

Second, if consumer i maintains his used unit in the second period he should be similarly indifferent between this behavior and purchasing a new unit in the second period from another firm at price c and m_1^* units of maintenance at price m_1^*. Using arguments similar to those above yields that each consumer i who maintains his used unit purchases $m_2^*(z_i)$ units of maintenance and $p_{j2}'(m_2^*(z_i),z_i) =c+m_1^*+\Delta+f(m_1^*)-(1+z_i)f(m_2^*(z_i))$. Further, firm j's profit in selling to this consumer is $c+m_1^*+\Delta+ f(m_1^*)-(1+z_i)f(m_2^*(z_i))-m_2^*(z_i)$.

Third, we know firm j receives Δ when one of its first-period consumers purchases a new unit from the firm, while the firm receives $c+m_1^*+\Delta+f(m_1^*)-(1+z_i)f(m_2^*(z_i))-m_2^*(z_i)$ when the consumer maintains his used unit. Let z'' be such that $\Delta=c+m_1^*+\Delta+f(m_1^*)-(1+z'')f(m_2^*(z''))-m_2^*(z'')$. Since this equation is equivalent to the condition that defines z^* (see the proof of Proposition 1) we have $z''=z^*$. We now have that firm j's strategy should be such that consumer i purchases a new unit from firm j if $z_i>z^*$ and maintain his used unit if $z_i<z^*$ (both behaviors are optimal when $z_i=z^*$). π_{j2}^{M*} denotes firm j's second-period profit when all three conditions are satisfied.

Given the above, firm j's behavior in the second period is characterized by $P_{j2}^M+p_{j2}(m_1^*)=c+m_1^* +\Delta$ and $p_{j2}'(m_2^*(z_i),z_i)=c+m_1^*+\Delta+f(m_1^*)-(1+z_i)f(m_2^*(z_i))$ for all $z_i<z^*$. Call these conditions A and B. There are three steps to the argument. First, from above we know conditions A and B must be satisfied for the firm to extract all the potential surplus in the second period. Second, let consumer i again be a consumer who purchased a new unit from firm j in the first period. Further, let conditions A and B be satisfied and, in addition, suppose $P_{j2}^M+p_{j2}(m\neq m_1^*)=\infty$, $p_{j2}(m\neq m_2^*(z_i),z_i)=\infty$ for all z_i, and $p_{j2}'(m_2^*(z_i),z_i) =\infty$ for all $z_i\geq z^*$. Faced with these prices an optimal strategy for consumer i is to behave as described above, i.e., maintain his used unit by purchasing $m_2^*(z_i)$ units of maintenance from firm j when $z_i<z^*$ and purchase a new unit and m_1^* units of maintenance when $z_i\geq z^*$. Since the above described behavior for consumer i is optimal from firm j's perspective, we have that there is at least one equilibrium to the second-period subgame that satisfies conditions A and B.

The third step is to show that there is no equilibrium to the second-period subgame that does not satisfy these conditions. Such a strategy necessarily yields a second-period profit level for firm j less than π_{j2}^{M*}. Let $P_{j2}^M+p_{j2}(m_1^*)=c+m_1^*+\Delta-\varepsilon$, $p_{j2}'(m_2^*(z_i),z_i)=c+m_1^*+\Delta+f(m_1^*)-(1+z_i)f(m_2^*(z_i))-2\varepsilon$ for all $z_i<z^*$, $P_{j2}^M+p_{j2}(m\neq m_1^*)=\infty$, $p_{j2}'(m\neq m_2^*(z_i),z_i)=\infty$ for all z_i, and $p_{j2}'(m_2^*(z_i),z_i)=\infty$ for all $z_i\geq z^*$. By setting ε sufficiently small the firm can guarantee a second-period profit level strictly higher than any level strictly less than π_{j2}^{M*}. Hence, any pricing strategy that does not satisfy conditions A and B cannot be part of an equilibrium to the second-period pricing game for firm j because there is always an alternative strategy that necessarily increases the firm's second-period profit level.

We now have that a consumer who buys a new unit in the first period from a firm that monopolizes the maintenance market for its own product behaves efficiently in the second period. This immediately yields that in the first period all consumers purchase from firms that monopolize the maintenance markets for their own products. The reason is that, starting from any set of strategies by the firms such that this is not the case, a firm could deviate and earn strictly positive profits. In this deviation the firm would monopolize the maintenance market for its own product and offer first-period prices for a new unit and m_1* units of maintenance such that each consumer i's expected net benefit over the two periods equals $EU_i^*-\varepsilon>EU_i^C$. It is similarly the case that all consumers in the first period must purchase m_1* units of maintenance from the firms they purchase new units from in the first period.

We also know, given that each firm j that sells a strictly positive number of new units in the first period earns strictly positive profits in the second, the zero-profit condition yields that for each such firm $P_{j1}^M+p_{j1}(m_1^*)<c+m_1^*$. Finally, we have that first-period consumption decisions are the same here as in the benchmark case, while second-period replacement and maintenance decisions are the same here as in the benchmark case. This means each consumer's expected gross benefit is the same here as in the benchmark case, while in combination with the zero-profit condition for firms it also means that each consumer's aggregate expected payments over the two periods is the same as in the benchmark case. Thus, $EU_i^M=EU_i^*>EU_i^C$ for all i.

Proof of Proposition 3: We start by showing there is an equilibrium of the type described and then argue that it must be unique. Suppose each consumer's first-period strategy is such that, if the consumer purchases a new unit, then it purchases the unit from the firm that offers a new unit at the lowest price, where if multiple firms are tied at the lowest price then the consumer chooses randomly among these firms. Further, let firm j be a firm that sells a strictly positive number of new units in the first period. Arguments similar to those in the proof of Proposition 1 yield that there is a unique optimal value for P_{j2}^C that satisfies $c<P_{j2}^C\leq c+\Delta$ (see footnote 14), where P_2^C denotes the shared value for P_{j2}^C. Further, because consumers in the first period are randomly choosing among the firms that offer the lowest price, all firms that sell a strictly positive number of new units in the first period must have the same price that we denote P_1^C. In turn, since $P_2^C>c$, the zero expected profit condition yields $P_1^C<c$.

Now consider the second-period behavior of consumer i who purchased a new unit in the first period. This consumer has four choices. First, he could upgrade the unit in which case his second-period net benefit equals $(1+\alpha)v_i-x_i-c_U$. Second, he could replace his used unit with a new unit produced by j_i in which case his second-period net benefit equals $(1+\alpha)v_i-P_2^C$. Third, he could replace his used unit with a new unit produced by another firm in which case his second-period net benefit equals $(1+\alpha)v_i-\Delta-c$. Fourth, he could decide not to purchase an upgrade or purchase a replacement unit in which case his second-period net benefit equals v_i.

Since $v_L\alpha-\Delta>c$, we know the consumer never chooses the fourth option. Let x' be such that $(1+\alpha)v_i-x'-c_U=(1+\alpha)v_i-P_2^C$. Since $c<P_2^C\leq c+\Delta$, we have the following. The consumer purchases an upgrade when $x_i\leq x'$, replaces the used unit with a new unit produced by j_i when $x_i>x'$ and $P_2^C<c+\Delta$, and replaces the used unit with a new unit produced by j_i or a new unit produced by a different firm when $x_i>x'$ and $P_2^C=c+\Delta$ (see footnote 16). Note, since $x^*=c-c_U$ and $P_2^C>c$, we have $x'>x^*$.

Suppose there exists a firm j that sells a strictly positive number of new units in the first period, chooses $P_{j2}^C=c+\Delta$, and has a strictly positive expected number of its first-period consumers replace their used units in the second period with new units purchased from other firms. Then the firm could increase its second-period profit by infinitesimally lowering P_{j2}^C below $c+\Delta$ since then all of its first-period consumers who purchase new units in the second period would purchase these units from firm j. This means that in equilibrium all of firm j's first-period consumers who purchase new units in the second period must purchase from firm j.

Since the above argument holds for every firm j that sells a strictly positive number of new units in the first period, we have the following. First, in the second period each consumer i who purchased a new unit in the first period for whom $x_i \leq x'$ purchases an upgrade. Second, in the second period each consumer i who purchased a new unit in the first period for whom $x_i > x'$ purchases a new unit from firm j_i. Third, every consumer i purchases a new unit in the first period since $v_L > c$.

Now consider U_i^C and U_i^*. We know $U_i^*=v_i-c+\beta[(1+\alpha)v_i-c_U-x_i]$ if $x_i \leq x^*$ while $U_i^*=v_i-c+\beta[(1+\alpha)v_i-c]$ if $x_i > x^*$. We further know $U_i^C=v_i-P_1^C+\beta[(1+\alpha)v_i-c_U-x_i]$ if $x_i \leq x'$, while $U_i^C=v_i-P_1^C+\beta[(1+\alpha)v_i-P_2^C]$ if $x_i > x'$. Given $x' > x^*$ and $P_1^C < c$, we now have $U_i^C > U_i^*$ if $x_i \leq x^*$. Also, since the zero profit condition that defines the relationship between P_1^C and P_2^C tells us that $c-P_1^C < \beta(P_2^C-c)$, we have $U_i^C < U_i^*$ if $x_i > x'$. For $x^* < x_i \leq x'$, $U_i^C-U_i^*$ is given by (A7).

$$U_i^C-U_i^*=(c-P_1^C)+\beta[(c-c_U)-x_i] \tag{A7}$$

Since the two expressions for U_i^* are equal at x^* and the two expressions for U_i^C are equal at x', we have $U_i^C-U_i^*>0$ at $x_i=x^*$, $U_i^C-U_i^*<0$ at $x_i=x'$, while equation (A7) tells us that $U_i^C-U_i^*$ is strictly decreasing between x^* and x'. Hence, there must exist a value x'', $x^*<x''<x'$, such that $U_i^C-U_i^*>0$ if $x_i<x''$, $U_i^C-U_i^*<0$ if $x_i>x''$, and $U_i^C-U_i^*=0$ if $x_i=x''$.

Now consider ΣU_i^* and ΣU_i^C. Without loss of generality let the total number of consumers in the population equal one. ΣU_i^* is then given by (A8), where v^+ is the average value for v_i.

$$\Sigma U_i^*=v^+-c+\beta[(1+\alpha)v^+-\int_{x_L}^{x^*}(x+c_U)h(x)dx-\int_{x^*}^{x_H}ch(x)dx] \tag{A8}$$

ΣU_i^C is given by (A9).

$$\Sigma U_i^C=v^+-P_1^C+\beta[(1+\alpha)v^+-\int_{x_L}^{x'}(x+c_U)h(x)dx-\int_{x'}^{x_H}P_2^C h(x)dx] \tag{A9}$$

Given competition means in equilibrium all durable goods producers earn zero expected profits, we know $P_1^C+\beta\int_{x'}^{x_H}P_2^C h(x)dx=c+\beta\int_{x'}^{x_H}ch(x)dx$. Substituting this into (A9) yields (A10).

$$\Sigma U_i^C=v^+-c+\beta[(1+\alpha)v^+-\int_{x_L}^{x'}(x+c_U)h(x)dx-\int_{x'}^{x_H}ch(x)dx] \tag{A10}$$

Given $x'>x^*=c-c_U$, a comparison of (A8) and (A10) yields $\Sigma U_i^*>\Sigma U_i^C$.

We now argue that each consumer i's first-period strategy concerning who to purchase from is an optimal strategy. We know from above that, given all other consumers are randomly choosing among the firms offering a new unit at the lowest price in the first period, then all such firms will have the same price for a new unit in the second period where this price is less than or equal to $c+\Delta$. Further, suppose all firms that charge more than the lowest price in the first period have a second-period strategy of charging $c+\Delta$ for a new unit (since this situation is off-the-equilibrium path we can specify any price here). Then it is clear that randomly choosing among the firms offering a new unit at the lowest price in the first period is optimal. Combining this with our assumption that consumers treat firms that employ the same strategy in an equivalent way (see footnote 17), we have that if all new units in the first period are sold at the same price then i) through v) constitute the unique equilibrium

The final step is to argue that in any equilibrium all new units in the first period must be purchased at the same price. Suppose this is not the case and consider two firms each of which sells a strictly positive number of new units in the first period, where firm A charges a low price and firm B charges a high price. We know that no consumer who plans to purchase an upgrade in the second period will purchase from firm B. Further, firm A cannot just sell to consumers who plan to purchase an upgrade because then the zero profit condition implies that its first-period price must be c, but using arguments similar to above yields that B's first-period price must be less than c.

The only other possibility is that firm A sells to a mix of individuals who anticipate purchasing new units and those who upgrade while B only sells to those who anticipate purchasing new units. But if both firms sell to consumers who purchase new units in the second period, then the first-period present discounted expenditure associated with purchasing a new unit in each period must be the same across the two firms. But this means one of the firms violates zero expected profits. To see this suppose firm B satisfies zero expected profits. Then firm A earns zero expected profits in selling to consumers in the first period who purchase new units in the second. But since the firm also sells some units in the first period at a price less than c to consumers who do not purchase new units in the second period, overall profits must be negative.

<u>Proof of Proposition 4</u>: We first show that there is an equilibrium that satisfies i) through v) in which all consumers for whom $x_i>x^*$ purchase in the first period from firms that monopolize the upgrade markets for their own products, while all consumers for whom $x_i\leq x^*$ purchase in the first period from firms that do not monopolize the upgrade markets. Suppose this is the case and consider firms that sell a strictly positive number of new units in the first period and do not monopolize the upgrade markets. Consumers for whom $x_i\leq x^*$ clearly purchase upgrades in the second period at a price c_U, which in combination with zero profits means each of these firms charges c for a new unit in the first period. Now consider firms that sell a strictly positive number of new units in the first period and monopolize the upgrade market. Following arguments similar to those in the proof of Proposition 2, in the second period such a firm will price new units and upgrades so as to extract all of the potential surplus from its first-period consumers. This means the new-unit price is $c+\Delta$, the upgrade price is at least $c_U+\Delta$, and all consumers for whom

x_i>x* purchase new units in the second period from the same firm they purchased from in the first. In turn, the zero-profit condition implies that each of these firms has a first-period price equal to c-βΔ. Note further that there must be at least two such firms, because otherwise, the firm selling at the price c-βΔ in the first period would want to raise its price. Also, since in this equilibrium each consumer i makes the same consumption decisions as in the benchmark case and over the two periods each consumer i's total payment in the same as in the benchmark case, it is immediate that in this equilibrium $U_i^M=U_i^*$ for all i and $\Sigma U_i^M=\Sigma U_i^*$.

To show this is an equilibrium we need to show two conditions hold. First, no consumer can be strictly better off by switching firms. Consider a consumer for whom $x_i \leq x^*$. Since the second-period upgrade price for a firm that monopolizes the upgrade market is at least $c_U+\Delta$, such a consumer cannot be made strictly better off by switching. Consider a consumer for whom $x_i>x^*$. Since if such a consumer switched he would pay at least c for a new unit in the second period (and the first-period price would be c), this consumer can also not be made strictly better off by switching. Second, no firm can offer a lower first-period price, attract both types of consumers, and earn strictly positive profits. This follows from the fact that each consumer is initially receiving the benchmark or first-best utility level. That is, the definition of the first best means that a firm cannot earn strictly positive profits and have each consumer who purchases from it receive at least U_i^*.

We now turn to other equilibria. Arguments similar to those above yield that there are other equilibria that are identical to the one described above except that in the first period some consumers for whom $x_i \leq x^*$ purchase from firms that monopolize the upgrade market, where these firms charge $c_U+\Delta$ for an upgrade in the second period (an upgrade price of $c_U+\Delta$ in the second period can be optimal if most of these consumers have values for x_i that are sufficiently close to x*). Note that, if $x_i \leq x^*$, then a consumer will be indifferent between purchasing in the first period from a firm that does not monopolize the upgrade market and charges c (in which case the consumer upgrades in the second period at a price c_U) and from a firm that monopolizes the upgrade market and charges c-βΔ if the anticipated upgrade price is $c_U+\Delta$ (in which case the consumer upgrades in the second period at a price $c_U+\Delta$).

The final step is to show that no other equilibrium exists. A firm that does not monopolize the upgrade market will clearly be willing to offer a new unit in the first period at a price c, while a firm that monopolizes the upgrade market will clearly be willing to offer a new unit in the first period at a price c-βΔ (since the firm will earn at least Δ from each purchaser in the second period). This implies that any equilibrium must satisfy $U_i^M \geq U_i^*$ for all i. But the definition of the first best and the fact that firms cannot earn negative profits in equilibrium reduces this condition to $U_i^M=U_i^*$ for all i, where consumers for whom $x_i>x^*$ purchase new units in the first period while those for whom $x_i<x^*$ purchase upgrades.

Given this, suppose some consumers for whom $x_i>x^*$ purchase from a firm that does not monopolize the upgrade market. The zero profit condition implies the first-period price must be less than c, but then consumers for whom $x_i<x^*$ can purchase from this firm and receive $U_i^M>U_i^*$. So any equilibrium must have all consumers for whom $x_i>x^*$ purchase from a firm that monopolizes the upgrade market. But given this and that these consumers pay $c+\Delta$ in the second period for a new unit, $U_i^M=U_i^*$ for all i implies the first-period price must be $c-\beta\Delta$. Finally, if all consumers for whom $x_i<x^*$ must receive $U_i^M=U_i^*$, then each of these consumers must satisfy one of the following two conditions. Either the consumer purchases a new unit in the first period from a firm that does not monopolize the upgrade market and pays c, or the consumer purchases in the first period from a firm that monopolizes the upgrade market and pays $c-\beta\Delta$ for a new unit in the first period and $c_U+\Delta$ for an upgrade in the second period (such a consumer could not pay less in the first period because then consumers for whom $x_i>x^*$ would want to purchase from that firm, and they cannot pay more in the first period because then the consumer would receive less than U_i^* over the two periods).

<u>Proof of Proposition 5</u>: Let us begin with period 3. Let n_{13} be the number of consumers who start period 3 with no unit, n_{23} be the number who start period 3 with a unit that has a used part that is not worn out, n_{33} be the number who start period 3 with a unit that has a used part that is worn out, x_{m3} be the number of worn out parts owned by the monopolist at the beginning of the period, x_{r3} be the number of worn out parts owned by the competitive remanufacturers at the beginning of the period, and let π_3 denote period 3 monopoly profitability.

Because $p_2>p_1$, it must be the case that $x_{m3}+x_{r3}<n_{33}$ (this follows since every used unit in the second period will also be a used unit in the third period, and some used units in the third period have a probability p_2 of having a worn out part while every used unit in the second period has a probability p_1 of having a worn out part). To maximize π_3 the monopolist will do the following. First, if $n_{13}>0$ the monopolist will set a price for a new unit equal to v to extract all of the surplus from each consumer who does not own a used unit at the beginning of the period, and each such consumer purchases a new unit from the monopolist. Second, if $n_{33}>0$ the monopolist will set a price for a new part equal to M+y in order to extract all of the surplus from consumers who purchase new parts from the monopolist and, because new and remanufactured parts are perfect substitutes, remanufactured parts also sell for M+y. The result is that every consumer with a worn out part purchases either a new part or a remanufactured part and scraps the worn out part. We now have that third-period monopoly profitability is given by $\pi_3=n_{13}(v-c)+x_{m3}(M+y-c_r')+(n_{33}-x_{m3}-x_{r3})(M+y-c_p)$.

Now consider period 2. Let n_{12} be the number of consumers who start period 2 with no unit, n_{22} be the number of consumers who start period 2 with a unit that has a used part that is not worn out, n_{32} be the number of consumers who start period 2 with a unit that has a used part that is worn out, and let π_2 be the present discounted value of the firm's flow of profits over periods 2 and 3. There are two cases. Suppose $n_{12}=1$. From before we know that a consumer who does not purchase a new unit in the second period has expected consumer surplus over the second and third periods equal to zero. Given this and the equilibrium behavior in the third period described above, a consumer will be willing to pay up to $(1+\beta)v-$

$\beta p_1 M$ for a new unit in the second period. Given this and the equilibrium behavior in the third period described above, the result is that the monopolist charges $(1+\beta)v-\beta p_1 M$ for a new unit in the second period, every consumer purchases a new unit in the second period, and $\pi_2=(1+\beta)v-c+\beta p_1(y-c_p)$.

Now suppose $n_{12}<1$. As before, the monopolist will set the price for a new unit in the second period equal to $(1+\beta)v-\beta p_1 M$ and every consumer who does not own a new unit at the beginning of the period will purchase a new unit from the monopolist. Further, given our analysis of period 3, competition among competitive remanufacturers yields that these firms will offer $\beta(M+y-c_r)$ for a worn out part in the second period. Given this and assuming the monopolist sells a new part to every consumer who owns a worn out part, in the second period the monopolist has three relevant options in terms of the price it sets for a new part and the core charge. These three options are as follows.

First, the monopolist could set the core charge sufficiently low that it does not repurchase any worn out parts and set $P_2^p=M+\beta(M+y-c_r)$. This yields $\pi_2=n_{12}[(1+\beta)v-c+\beta p_1(y-c_p)]+n_{32}[M-c_p+\beta(M+y-c_r)]+\beta A[M+y-c_p]$, where $A=p_2n_{22}+p_1n_{32}+p_1n_{12}-n_{32}$ (note that since $n_{12}+n_{22}+n_{32}=1$, $p_2>p_1$, and $n_{32}\leq p_1$, we know $A>0$). Second, the monopolist could purchase some but not all of the worn out parts. This means $P'=\beta(M+y-c_r)$ and $P_2^p=M+\beta(M+y-c_r)$ (note that any lower core charge means the monopolist purchases no worn out parts while any higher core charge means it purchases all of the worn out parts). Let x denote the number of worn out parts purchased. This yields $\pi_2=n_{12}[(1+\beta)v-c+\beta p_1(y-c_p)]+n_{32}[M-c_p+\beta(M+y-c_r)]+\beta A[M+y-c_p]+\beta x(c_r-c_r')$. Third, the monopolist could set the core charge sufficiently high that it purchases all of the worn out parts. This means $P'\geq\beta(M+y-c_r)$ and $P_2^p=M+P'$ (note that $P'=\beta(M+y-c_r)$ is consistent with the monopolist purchasing no worn out parts, some worn out parts, and all of the worn out parts). This yields $\pi_2=n_{12}[(1+\beta)v-c+\beta p_1(y-c_p)]+n_{32}[M-c_p+\beta(M+y-c_r)]+\beta A[M+y-c_p]+\beta n_{32}(c_r-c_r')$. Since $n_{32}>x$ and $c_r>c_r'$, the monopolist will choose the last option.

We now allow the monopolist not to sell a new part to every consumer with a worn out part in the second period. There are two options here. First, suppose the monopolist sells no new parts in the second period. From our analysis of period 3 we know that in this case $\pi_2=n_{12}[(1+\beta)v-c+\beta p_1(y-c_p)]+\beta n_{32}[M+y-c_p]+\beta A[M+y-c_p]$. Given $c_p-y<M$ and $y<\beta(c_p-c_r)$, this option is worse than the best option when the monopolist sold a new part to every consumer with a worn out part in the second period. The other option is that the monopolist sells new parts to some of the consumers in the second period with worn out parts. Let x now denote the number of new parts sold. Using arguments similar to those above, in this case the best the monopolist can do is purchase a worn out part from every consumer to whom it sells a new part. Given this, this option yields $\pi_2=n_{12}[(1+\beta)v-c+\beta p_1(y-c_p)]+\beta(n_{32}-x)[M+y-c_p]+x[M-c_p+\beta(M+y-c_r)]+\beta A[M+y-c_p]+\beta x(c_r-c_r')$. Again, given $c_p-y<M$ and $y<\beta(c_p-c_r)$, this option is also worse than the best option when the monopolist sold a new part to every consumer with a worn out part in the second period. We thus have $P'\geq\beta(M+y-c_r)$, $P_2^p=M+P'$, and every consumer with a worn out part purchases a new part from the monopolist and sells the worn out part to the monopolist.

Now consider period 1. From before we know that a consumer who does not purchase a new unit in the first period has expected consumer surplus over the three periods equal to zero. Given this and the equilibrium behavior in the second and third periods described above, a consumer will be willing to pay up to $(1+\beta+\beta^2)v-\beta p_1M-\beta^2 p_1^2M-\beta^2(1-p_1)p_2M$ for a new unit in the first period. Given this, $c>>c_p$, and the equilibrium behavior in the second and third periods described above, the result is that the monopolist charges $(1+\beta+\beta^2)v-\beta p_1M-\beta^2 p_1M-\beta^2(1-p_1)p_2M$ for a new unit in the first period, every consumer purchases a new unit in the first period, and $\pi^m=(1+\beta+\beta^2)v-c-\beta p_1c_p+(\beta^2p_1^2+\beta^2(1-p_1)p_2)(y-c_p)+\beta^2p_1(c_p-c_r')$. Notice that this means every consumer has expected consumer surplus over the three periods equal to zero, i.e., $EU^m=0$.

The only thing left to prove is the two comparisons in v) concerning the benchmark equilibrium. Using arguments similar to those above yields that the benchmark equilibrium is the same as that characterized above except that in the second period every consumer with a worn out part sells the part to a competitive remanufacturer at a price $\beta(M+y-c_r)$ and then these parts are remanufactured and sold in the third period by the competitive remanufacturers at the price M+y. Hence, since from the standpoint of consumers the only changes are that in the second period they are selling their worn out parts to different firms (but at the same price) and that in the third period they are buying the remanufactured parts from different firms (but at the same price), there is no effect on consumer welfare, i.e., $EU^m=EU^*=0$. Further, since the monopolist is no longer participating in the remanufacturing market, monopoly profitability is now given by $\pi^*=(1+\beta+\beta^2)v-c-\beta p_1c_p-(\beta^2p_1^2+\beta^2(1-p_1)p_2)(y-c_p)+\beta^2p_1(c_p-c_r)$. Since $c_r>c_r'$, we have $\pi^m>\pi^*$.

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