

**Analyzing Welfare in Related Markets:  
Durable Goods and Aftermarkets**

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August, 1997

**Abstract:** The "aftermarkets" literature focuses on two important questions: (1) do durable goods manufacturers that control their aftermarkets have an incentive to charge service prices that exceed costs?; (2) how significant (in a welfare sense) is this distortion? Unlike previous work, this paper addresses the latter question by explicitly modeling firm behavior under various market structure conditions. The most interesting result from this analysis is that conditions of upstream competition and aftermarket control result in *lower* welfare than system monopoly. In the former case relative price distortions raise equipment lifecycle costs. A system monopolist, on the other hand, sets prices so that users of equipment minimize these costs.

**JEL codes: L40, D40**

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The views expressed herein do not necessarily represent those of the US Department of Justice.

In a number of recent US antitrust cases, aftermarket behavior by manufacturers has received considerable attention. Efforts by durable goods manufacturers to control the provision of service in their respective aftermarkets have prompted lawsuits by service competitors and antitrust authorities. Often, manufacturers are accused of tying the sale of a proprietary product, e.g. replacement parts, to a competitively supplied input, e.g. labor (Eastman Kodak v. Image Technical Service, 112 S. Ct. 2072 (1992), for example). In other cases, manufacturers are sued for restrictive licensing practices that allegedly contributed to aftermarket foreclosure (United States v. General Electric Co., 1997-1 Trade Regulation Reports, ¶ 71,765 p. 79407). Plaintiffs claim that this behavior results in higher service prices for equipment owners (and in some instances, reduced upstream competition). Manufacturers defend their actions by arguing that any attempt to exploit their installed base customers would result in unacceptable losses in the upstream market for equipment.

This litigation has inspired a number of papers in the economic and legal literature that analyze firms' aftermarket incentives and behavior (see Shapiro (1995) for a partial listing). Of particular interest here are three papers, two by Borenstein, Mackie-Mason, and Netz (1995,1996), and the other by Shapiro (1995). Borenstein, et al. argue that firms in control of their aftermarkets often have an incentive to charge service prices that exceed costs. Their discrete-period model in both its finite- and infinite-horizon versions consists of a sequence of "two-period" stages during which buyers purchase and operate new equipment (the first period) and then decide whether to service the existing equipment or purchase new equipment (the second period). Since performing some positive amount of service is efficient (compared to substituting new machines whenever a breakdown occurs), manufacturers are able to raise aftermarket prices without inducing switching.<sup>1</sup> In the finite-horizon case, this is a dominant strategy for firms. As a consequence, equipment prices are below cost since firms compete for these aftermarket rents.

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<sup>1</sup> An important underlying assumption in this literature, and one with ample empirical support, is the inability of manufacturers to commit to competitive aftermarket prices. Although an explanation for this commitment problem is worthy of further research, it is outside the scope of this paper.

In the infinite-horizon case, a pure strategy equilibrium may not exist, and aftermarket pricing can oscillate as manufacturers attempt to build reputations as low-price service providers. In either case, relative prices are distorted to some degree. Since product durability may be influenced by the quantity of maintenance that is performed, "high" aftermarket prices and "low" equipment prices may result in product lifetimes that are too short, raising total lifecycle costs and reducing welfare.<sup>2</sup>

Shapiro (1995) acknowledges that manufacturers have an incentive to distort prices but is generally skeptical that the associated welfare losses are significant. In a technical appendix he defines a consumer "injury ratio" that compares the marginal increase in a buyer's lifecycle costs due to Borenstein-style price distortions with the marginal cost increases arising from monopoly control of equipment *and* service markets ("system monopoly"). Using a multi-period model of equipment lifecycle costs in which product lifetime is endogenous, he concludes that this ratio is generally small because aftermarket overcharges are "rebated" through equipment discounts. However, this consumer-based measure of welfare ignores the possibility that *total* welfare is reduced compared to the system monopoly case, i.e. social costs may be *lower* with monopoly. Furthermore, the injury ratio measure may itself be flawed. The denominator in this ratio -- the marginal cost increases arising under system monopoly -- assumes that marginal changes in aftermarket prices do not affect equipment pricing. But why should this be true? Since the model incorporates no demand structure it is not apparent under what conditions this claim holds.

This paper extends these previous efforts by examining how total welfare varies with market structure. Using a variant of Shapiro's model that accounts for buyer demand, I consider

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<sup>2</sup> Note, however, that Borenstein, et al. do not explicitly model lifecycle costs -- the discrete periods in their model are fixed in duration -- and therefore cannot fully analyze changes in welfare arising from a change in relative prices.

welfare in three different cases: (1) competitive equipment and service markets, (2) system monopoly, and (3) competitive equipment market, with manufacturers possessing market power in their respective aftermarkets. For cases (1) and (3) I also examine the effect of introducing equipment-specific switching costs. The analysis indicates that, compared to the case of system monopoly, welfare is generally *lower* when firms in control of their aftermarkets face upstream competition. This is because a system monopolist sets prices that result in optimal product lifetimes: by ensuring that costs are minimized, its profits can be maximized. I also find, however, that the introduction of switching costs creates the possibility, albeit small, that case (3) situations can be as efficient as those with a system monopolist. And when compared to the benchmark case of competition in both markets, case (3) situations actually result in *higher* welfare for a range of parameter values. The intuition here is that when firms control their aftermarkets, the existence of switching costs permits them to charge high enough equipment prices to mitigate the effects of price distortion on product lifetimes.

### 1. *Preliminaries*

Before describing the model in detail it is useful to characterize some key elements of the underlying durable good market and associated aftermarket. Shapiro (1995) identifies three: (1) the user purchases several complementary items that work together as a "system"; (2) these components are purchased at different points in time (due to an inability and/or unwillingness of users to contract *ex ante* for a complete system); (3) there is some degree of "lock-in" or sunk costs. For example, in the case of medical imaging equipment, the initial component is the diagnostic device itself, e.g. an MRI device, and the components purchased later may include spare parts, hardware and software upgrades, associated labor, etc. The sunk costs consist primarily of vendor-specific human capital investments for operation and maintenance of the device. Note, however, that although related markets of this sort are widespread, significant sunk costs are not always present, e.g. for most consumers, the sunk costs associated with the use of automobiles are trivial. Nonetheless, I will argue that the price distortions arising when firms control their aftermarkets are still present when switching costs are zero (and is true for the case of automobiles). For this reason, the analysis distinguishes between situations with and without

switching costs.

## 2. *The Model*

In each case examined here, a firm manufactures equipment at a cost  $K$ , and provides aftermarket service for its own equipment at a cost of  $c$  per unit.<sup>3</sup> Other service organizations can provide service for this equipment at a cost  $c_{so} \geq c$ . If switching costs,  $s$ , are zero, buyers perceive all firms' equipment as identical; if  $s > 0$ , these different firms' equipment are *functionally* equivalent, i.e. their performance characteristics are identical, but sunk costs are vendor-specific.

As equipment ages, the service requirements necessary to achieve a given level of performance increase and, are assumed to grow linearly with time.<sup>4</sup> That is, a machine  $t$  years old requires  $t$  units of service. These increasing costs provide an incentive for owners to replace equipment.

I assume that each buyer requires the use of one machine for the indefinite future, with a valuation of  $D$  per unit time. Buyers choose to replace aging equipment with new equipment in order to minimize total lifecycle costs. The length of this replacement cycle,  $T$ , depends on the prices for equipment and service,  $E$  and  $p$ , respectively, and a discount factor,  $r$  (without loss of generality, all buyers are assumed to be "in phase", i.e. they replace equipment at the same instant in time). Firm(s) set these prices to maximize profits over the infinite horizon, using the same discount factor.

To solve these optimization problems I proceed in the normal fashion. First, I solve the buyer's problem. Second, I use this result to determine a firm's optimal price-setting strategy. This strategy will vary according to competitive circumstances.

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<sup>3</sup> To simplify the analysis, it is assumed that the various aftermarket system components are used in fixed proportions, and hence, can be analyzed as a composite good. This formulation is employed in previous work.

<sup>4</sup> This linear specification is used by Shapiro.

Suppose then that a buyer operates a machine for a length of time  $T$ . Total costs over that period of time are

$$C = E + p \int_0^T t e^{-rt} dt$$

With a replacement cycle of  $T$ , a new machine is purchased every  $T$  years. The total discounted

$$TC = \frac{C}{1 - e^{-rT}}$$

cost associated with this schedule, including service expenditures, is

One method for obtaining the optimal replacement cycle involves differentiating the total cost expression with respect to  $T$  and setting the result equal to zero. After several steps of algebra, the following expression for the optimal  $T^*$  is obtained:

$$\frac{r^2 E}{p} = e^{-rT^*} + rT^* - 1 \quad (1)$$

Although no exact analytic solution for  $T^*$  exists in this case, an approximate solution can be obtained (since  $rT^*$  is likely to be small) by replacing the exponential in (1) with the first three

$$T^* \approx \sqrt{\frac{2E}{p}} \quad (2)$$

terms of its corresponding Taylor series expansion. We then find that

Note that the optimal replacement cycle is increasing in  $E$ , decreasing in  $p$ , and independent of  $r$ .

That is, as the relative cost of equipment increases, users have more service performed, and  $T^*$  is longer. By contrast, when the relative cost of service rises, users buy less service and  $T^*$

declines.

A more exact though less general approach to this problem involves obtaining numerical values for  $T$  that satisfies (1). By varying  $E/p$  for a particular value of  $r$ , a set of  $T^*$  values is generated that can then be used to estimate an exact  $T$  function. Using an  $r$  of 0.1 and integer values of  $E/p$  ranging from 1 to 20 I obtained corresponding values for  $T^*$ . I then regressed  $\ln T$  on a constant and  $\ln(E/p)$ ; the  $R^2$  for this estimation exceeds 0.999. The parameter results imply the following relationship:

$$T^*(r = 0.1) = \left( \frac{1.96502 E}{p} \right)^{0.52974} \quad (3)$$

One can check that the  $T$  values generated by (3) are always larger than those from (2) (and the difference is increasing in  $E/p$ ).<sup>5</sup> For example, if  $E/p = 10$ , the "approximate" product cycle is of length 4.47 whereas the "exact" solution equals 4.84. The intuition is that when  $r > 0$ , buyers discount future aftermarket expenditures, lowering their effective cost and this in turn lengthens the optimal product cycle. Note that the optimal  $T^*$  is obtained when  $E/p$  equals  $K/c$ .

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<sup>5</sup> Similar results are obtained for other values of  $r$ .

## *The Firms' Price Strategies:*

### *A. Competitive Equipment- and After-markets*

#### 1. No Switching Costs

When both markets are competitive price determination is trivial:  $E = K$  and  $p = c$ . With competitive pricing, the replacement cycle is efficient, i.e. costs are minimized when (using (2))

$$T^* = \sqrt{\frac{2K}{c}}$$

#### 2. Switching Costs

Switching Costs permit firms with an installed base to enjoy positive profits.<sup>6</sup> Since the switching costs are equipment- and not service-specific, incumbent firms will set  $E = K + s$ , and  $p = c$  for their installed base, and  $E = K$  for other buyers (assuming that price discrimination is possible). In this unique equilibrium no switching occurs. Since  $E$  is too high,  $T^*$  is longer than optimal and welfare is reduced.

### *B. System Monopoly*

Given the (approximate) optimal response function,  $T^*$ , and buyers' identical valuations, a monopolist chooses  $E$  and  $p$  to maximize the follow expression:

$$\begin{aligned} \pi_{Total} &= \frac{\pi_T}{1 - e^{-r\sqrt{\frac{2E}{p}}}} \\ s.t. D \int_0^{\sqrt{\frac{2E}{p}}} e^{-rt} dt &\geq E + p \int_0^{\sqrt{\frac{2E}{p}}} te^{-rt} dt \end{aligned} \quad (4)$$

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<sup>6</sup> Of course, obtaining the installed base under competitive conditions implies below-cost pricing in the first product cycle to offset later profits. Thus, at first,  $T^*$  is too short.

where

$$\pi_T = (E - K) + (p - c) \int_0^{\sqrt{\frac{2E}{p}}} t e^{-rt} dt$$

That is, the monopolist's problem involves maximizing a discounted stream of profits from the sale of equipment and service, subject to the constraint that revenues during any period  $T^*$  are no greater than a buyer's valuation (this constraint will be binding).

In maximizing the Lagrangean expression corresponding to (4), three first order conditions are generated, 1.  $\partial L / \partial E = 0$ , 2.  $\partial L / \partial p = 0$ , and 3.  $\partial L / \partial \lambda = 0$ . Again, to obtain useful results exponential terms are replaced with the first three terms of the corresponding Taylor series. When this is done, and after considerable algebraic manipulation, the first two first order conditions reduce to:

$$\lambda = 1 + \frac{\frac{K}{2E} + \frac{p-c}{2p} - \frac{1}{2}}{\left[ 1 + r \left( \frac{E}{2p} \right)^{\frac{1}{2}} + \text{higher order terms in } r \right]} \quad \text{FOC \#1}$$

$$\lambda = 1 + \frac{\frac{1}{2} - \frac{K}{2E} - \frac{p-c}{2p}}{\left[ 1 - r \left( \frac{E}{2p} \right)^{\frac{1}{2}} + \text{higher order terms in } r \right]} \quad \text{FOC \#2}$$

For reasonable values of  $r$  the higher order terms in each denominator can be ignored. Equating the two conditions then gives

$$\frac{K}{c} = \frac{E}{p}$$

Thus, a monopolist (for "small"  $rT$ ) sets prices efficiently, i.e.  $T_{Monop} = T_{Comp}$ . That is, profits are maximized when the firm minimizes total lifetime (social) costs. Using this result, and the third FOC, the prices chosen by the monopolist can be determined. Note that since the Lagrangean constraint is binding, consumer welfare is less than in the pure competitive case.

Does this result hold for larger values of  $rT$ ? I make the following assertion: if a monopolist is able to employ an appropriate version of (3) in its optimization, it will set prices so that discounted costs are minimized, i.e.  $E/p = K/c$ . To (numerically) verify this claim I set  $r = 0.1$  in (4) and used (3) as the optimal response function. After obtaining exact expressions for  $\partial L/\partial E = 0$  and  $\partial L/\partial p = 0$ , I then substituted in values for  $K$ ,  $E$ ,  $c$ , and  $p$  that satisfied (1)  $E/p = K/c$  and (2) the requirement that profits be non-negative, and solved for the Lagrange multiplier ( $\lambda$ ) common to both first order conditions. If the above claim is true then the numerical value of  $\lambda$  should be the same for both equations. This result was observed, and should be generally true.

### C. *Competitive Equipment Market, "Monopolized" Vendor-Specific Aftermarkets*

Here we allow manufacturers to exercise some (limited) market power in servicing their own equipment. It is assumed that equipment firms enjoy a cost advantage in their respective aftermarkets. In each aftermarket, other service organizations offer service at a price  $p_{so} = c_{so} > c$ . Thus,  $p_{so}$  is an upper bound for  $p$ .

#### 1. No Switching Costs

In lieu of switching costs, competition in the upstream equipment markets is likely to result in

zero-profit equilibria. One possible equilibrium consists of an aftermarket price,  $p_{so} > c$ , and, since the equipment market is competitive,  $E < K$ , where  $E$  satisfies the following condition for each generation of equipment:

$$(E - K) + (p_{so} - c) \int_0^{T^*(E, p_{so}, r)} t e^{-rt} dt = 0$$

In other words, anticipated aftermarket rents are competed away in the upstream market at the beginning of each cycle. If the price pair  $\{E < K, p_{so} > c\}$  is an equilibrium,  $T^*$  is too short, and welfare is reduced.

Now let us check to see whether this price pair constitutes an equilibrium. In this case total costs are higher than when prices are set more efficiently, suggesting an opportunity exists for a pareto improvement. Suppose manufacturer  $A$  deviates from this equilibrium at some point in time by setting new prices ( $E > E^*$ ,  $p < p_{so}$ ) so that buyers would be slightly better off in the future. I assume that prices changes are observable with no lag.

There are two cases to consider. First, suppose these price changes occur during the aftermarket phase of the product cycle and as a consequence firm  $A$  loses profits on its installed base.<sup>7</sup> For this to be profitable, this loss must be offset by future, discounted profits. Future profits, of course, will depend on (1) buyers' expectations and (2) the response by other manufacturers. Like Borenstein, et al., I assume that buyers employ an informed, but unsophisticated method to predict future aftermarket prices: prices in period  $t+1$  are equal to the those observed at the end

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<sup>7</sup> Note that the absence of switching costs does *not* imply that a buyer is willing to immediately sell his machine if another vendor suddenly lowers its service price (and the incumbent firm does not respond in kind). Such behavior would actually cost more than continuing to operate the existing machine for some finite but non-zero period of time. Initially, the buyer would experience a first-order increase in capital costs but only a second-order decrease in service costs (the vendor with lower aftermarket prices charges more for equipment).

of the current period  $t$ .<sup>8</sup> If  $A$ 's discount rate is not too high, and other firms continue to charge  $\{E^*, p_{so}\}$  then  $A$ 's strategy will be profitable. During the next product cycle, buyers expect lower aftermarket prices from  $A$  and thus are willing to switch manufacturers and purchase equipment at a higher price. However, consider the response by other firms.

Consider next the response of other firms to a deviation in the aftermarket. Since buyers' prefer firm  $A$ 's prices, other firms will make no equipment sales in the next product cycle unless they at least match  $A$ 's prices during the same product cycle. The best response for another firm is to slightly undercut  $A$ .<sup>9</sup> This price undercutting continues until firms are indifferent between maintaining a high aftermarket price ( $p = p_{so}$ ) and adjusting  $E$  and  $p$  to win market share in future periods. Since firms can anticipate this outcome, there is no reason to undercut in the first place.

Now consider a similar deviation by firm  $A$  at the moment equipment sales are made (again,  $E > E^*, p < p_{so}$ ). Since expectations about aftermarket prices for the current cycle are determined by previous prices, buyers anticipate lower surplus if  $A$ 's equipment is purchased and do not accept  $A$ 's offer. Thus, the proposed pure strategy equilibrium exists, and can be shown to be unique.<sup>10</sup>

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<sup>8</sup> This assumption appears to be consistent with actual consumer behavior.

<sup>9</sup> This is true even if firm  $A$  deviates at the "end" of a product cycle. Faced with lower aftermarket prices, buyers will extend the life of existing equipment, allowing time for other firms to respond.

<sup>10</sup> For any other potential zero-profit equilibrium price pair,  $\{E > E^*, p < p_{so}\}$ , an individual firm would prefer to raise its aftermarket price to exploit its installed base.

Note that Borenstein, et al. analyze a similar situation but conclude that no pure strategy equilibrium exists. The explanation is that their model of pricing in the aftermarket is static. Firms cannot respond to a price change during a given product cycle and thus price deviations can be profitable in the short term.

## 2. Switching Costs

The existence of positive switching costs allows manufacturers with an installed base to enjoy profits in each period (with the exception of the first period). One possible set of equilibria consists of an aftermarket price,  $p_{so} > c$ , and, since incumbents can price discriminate in the competitive, upstream equipment market, an  $E(s)$  that satisfies the following condition for each generation of equipment:

$$(E - K) + (p_{so} - c) \int_0^{T(E, p_{so}, r)} t e^{-rt} dt = s$$

With positive switching costs,  $E$  is greater than in the previous section (where  $s = 0$ ). However, depending on the size of  $s$ ,  $E$  may be less than, equal to, or greater than  $K$ . Similarly, depending on the size of  $s$ ,  $E/p < K/c$  ( $T^*$  too short),  $E/p = K/c$  ( $T^*$  efficient) or  $E/p > K/c$  ( $T^*$  too long) may hold; note, however, that given  $r$  and  $p_{so}$ , the second of these three conditions holds for only a single value of  $s$ . Furthermore, if we compare this case with the benchmark provided by Case A (competition *with* switching costs) it becomes clear that there exists a range of values for  $s$  in which the former produces more desirable outcomes. For values of  $s$  in this interval firms that control their aftermarket set prices so that  $T^*$  is closer to the efficient value than in Case A (since  $E/p$  is closer to  $K/c$ ). This results in lower total lifecycle costs.

Finally, existence and uniqueness of the proposed equilibria -  $\{E(s), p_{so} > c\}$  - can be demonstrated using reasoning similar to that employed in the previous section.

### ***Discussion/Conclusions***

The "aftermarkets" literature focuses on two important questions for policy makers: (1) do durable goods manufacturers in control of their aftermarkets have an incentive to charge service prices that exceed costs?; (2) how significant (in a welfare sense) is this distortion? This paper addresses the latter question by explicitly modeling firm behavior under different market structure conditions. The most interesting result from this analysis is that conditions of upstream competition and aftermarket control result in *lower* welfare than system monopoly. In the former case relative price distortions raise equipment lifecycle costs. A system monopolist, on the other hand, sets prices so that users of equipment minimize these costs.

However, this result and others in the paper are not necessarily robust to changes in the underlying assumptions of the economic model. For example, the introduction of product differentiation and/or elastic product demand may alter our conclusions about the relative merits of specific market structures. This is an area worthy of additional research, both theoretical and empirical in nature.

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