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# Installed base management versus selling in monopolistic and competitive environments

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ABSTRACT

This paper compares the policy of selling a product to that of installed base management, in which the manufacturer leases the product to consumers, and bundles repair and maintenance services along with the product. We compare the two policies in a monopolistic setting when a firm uses either one of the policies, and when both policies are used by a single firm. We then compare the policies under competition first when two firms use identical products, and when two firms use vertically differentiated products. Our findings indicate that the selling option dominates the installed base option in a monopolistic environment, even for significant values of remanufacturing savings from the installed base policy. In a competitive environment, if two firms use identical products, we find that the two firms use only differentiated pure strategies (where one firm uses installed base management and the other uses selling), or the outcome is a mixed equilibrium, where each firm uses each pure strategy with a certain probability. We find that the firm using the installed base management policy in the duopoly with identical products performs better than the firm using the selling policy. In a competitive market where both firms use vertically differentiated products, we find that both firms can use both mechanisms of installed base management and selling in equilibrium. However, we find that the profits from the installed base segments of the two firms are higher than the profits from the selling segments. Our results indicate that the selling policy performs better in a monopolistic environment while the installed base policy performs better in a competitive environment.



## 1. Introduction

Installed base management, the policy in which a manufacturer leases the product to customers and bundles repair and maintenance services along with the product, is an old industry practice. From the manufacturer's perspective, she can gain revenues from the customer's use of the product, in addition to a stream of revenues from maintenance and servicing, while retaining ownership of the product. From the customer's perspective, he can pay a lower rent for the product during the period of use (compared to the price paid for owning the product), and can also gain the advantage of not paying for servicing or maintenance costs on an uncertain basis, e.g., when the product breaks down. Customers can also benefit from using a product based on the latest technology, rather than being "locked in" to a previous generation of the product. There are examples from various industries of manufacturers using the policy of installed base management. For instance, in the IT industry, IBM, Unisys Corporation and Sun Microsystems use the strategy of installed base management extensively (Vaas, 1999). Another prime example is Cisco's success in the Indian telecom market. Cisco's previous model was built on selling its products and offering its maintenance services using a servicing contract. In short, Cisco was a master at selling and moving boxes. Entering the very competitive Indian market required a completely new business model, and Cisco used a turn-key service solution in which customers were going to pay for products based on the period the products were leased for, with maintenance costs included in the leasing contract. Cisco realized that a model built on operating expenditures (OPEX) in preference to capital expenditures (CAPEX) would be the preferred vehicle for cash constrained operators. This new business model allowed Cisco to capture a high market share in a market where the original government monopoly has been replaced by a very competitive marketplace with customers having a choice from 6 -12 operators in different parts of India (Das Ghosal & Padmanabhan, 2009). A third

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example is the use of installed base management for vehicle fleets. Dawson (2014) reports that there is a dichotomy of practices in vehicle fleet management, where two kinds of contracts are primarily offered: the first kind of contract is the leasing with an all-inclusive maintenance contract, and the second kind of contract is selling the vehicle with a pay-as-you-go contract for servicing. In the all-inclusive maintenance contract that is effectively a representation of installed base management, the firm uses a policy of offering a fixed-cost, maintenance-inclusive contract hire package that charges a regular amount per month per vehicle to cover all routine SMR (service, maintenance and repair) costs whether required or not, and also include a level of built-in contingency for any ad hoc work that may be required. In contrast, in the pay-as-you-go service, a certain amount of servicing is included for free, and beyond the base usage, all servicing instances of the vehicles are charged to the consumers. In this paper, we study when the leasing policy with the flat-fee contract with all maintenance included should be used, and when the firm should sell the product to consumers with variable maintenance costs to be paid by the consumer as and when required.

In addition to facing a high degree of competition, firms such as Cisco operate in an industry of highly commoditized products. Cisco's offerings of bundles of products with services offers an opportunity for the firm to differentiate its offered services from competitors. In general, for durable products that are commoditized, e.g., electronic durables such as copiers, printers, the scope for differentiation from competitors along product features is not high, as the technology and the quality of components available from suppliers are almost uniform (features such as printing quality, processing power, maintenance costs, are not based on proprietary technology but on open industry standards). The trend towards bundling the product with maintenance services is a way for manufacturers to differentiate themselves from others in an industry with shrinking profit margins and intense competition. In the IT industry, several companies are developing technologies to help firms adopt installed base management and service their installed base population better and cheaper. There are a number of studies in the marketing literature that analyze the benefits of installed base management to the competitiveness of the firm (Dasgupta, Sidarth, & Silva-Risso, 2007). Desai and Purohit (1999) investigate how the proportion of leases and sales affects a manufacturer's ability to compete in the auto market, and find that the optimal proportion of leases and sales depends on the competitiveness of the market. Desai and Purohit (1998) show that selling may be better than leasing if sold units depreciate significantly faster than leased units. The choice between leasing and selling is also affected by the existence of complementary products, Bhaskaran and Gilbert (2005) show that when there are complementary products that exist or can be introduced in the future, the leasing mechanism works better than the selling mechanism in alleviating inter-temporal price discrimination problems for the customer. Erat and Bhaskaran (2012) show that the value of the products may be further enhanced by providing the option of upgrading the base product later, this also impacts the selling versus leasing decision. There are also a number of studies that consider maintenance contracts as a strategic tool for gaining higher market share. Day and Fox (1985) provide a menu of different service contracts offered by manufacturers, retailers and third parties, and identify successful contracting situations for maintenance services. Guiltinan (1987) provides a pricing framework for bundles of services and/or products. Padmanabhan and Rao (1993) compare the offering of extended service contracts to risk averse and risk neutral consumers, and find that risk averse consumers are more likely to purchase extended service contracts. Rabetino, Kohtamaki, Lehtonen, and Kostama (2015) analyze the impact of lifecycle services on the firm's competitiveness. While this stream of literature takes into account servicing contracts resulting in a higher customer utility, they do not account for the maintenance cost benefits of installed base management.

The manufacturer has a number of reasons to use the strategy of installed base management for durable products. Firstly, she can obtain a second revenue stream from servicing the product. Customers who use the manufacturer's servicing contract provide the manufacturer with a steady stream of revenues over the product's life-cycle (Lieckens, Colen, & Lambrecht, 2015; Wise & Baumgartner, 1999). The revenue from servicing the customer could be a significant source of income in industries such as the auto industry where profit margins are low (McGeer, 2004). A second advantage of using the installed base policy is the role of the maintenance contract. It creates brand loyalty for the manufacturer that extends into future generations of products (Hunsaker, 2000; Patterson, 1998). A third advantage for the manufacturer is that she can obtain economies of scale in servicing multiple customers by having a fixed team for providing maintenance services. The manufacturer also obtains from leasing the option to reuse parts from end-of-lease products in product remanufacturing.

Other examples of firms preferring leasing products to selling products include United Shoe Machinery Corporation, and Xerox for copiers (Waldman, 1997). Around 1960, Xerox was one of the first firms to introduce a policy of leasing only and of internalizing the maintenance of its copying machines. Manufacturers in the car industry have also practiced installed base management for more than a decade (Silvey, 2002). In the elevator industry, Thyssenkrupp and Otis (The Economist, 1996) used the installed base policy to transform themselves from pure manufacturers to service providers. In the economics literature, the aspect of leasing of the installed base management policy and its comparison to the selling policy has been studied extensively from the perspective of the durable goods monopolist. Waldman (2003) provides a broad survey of the extant literature. However, while this stream of literature on leasing in economics studies the inter-temporal benefits of leasing, it does not take into account the offering of maintenance services in conjunction with the leasing policy and its effects on competition.

In the operations literature, maintenance and repair policies have been studied to find optimal maintenance frequencies, contractual incentive structures, and to identify the best agents for maintenance. De Giovanni, Reddy, and Zaccour (2016) study incentive structures to increase the product rate of return for remanufacturing in closed-loop supply chains. Cohen and Whang (1997) consider a lifecycle model of a service contract, in conjunction with selling the product, in which the servicing contract is offered in competition with a third party operator. Yalabik, Chhajed, and Petruzzi (2014), Kim, Cohen, and Netessine (2007), Ryall and Sampson. (2009), and Tarakci, Tang, Moskowitz, and Plante (2006) study incentive issues for maintenance contracts when the service is offered by a third party provider, while Tseng, Tang, Moskowitz, and Plante (2009) study outsourcing maintenance contracts for new technology adoptions. Groenevelt, Pintelon, and Seidmann (1992) find optimal product lot sizes with machine breakdowns. Robotis, Bhattacharya, and Wassenhove (2012) study the case where a monopolist leases the product to consumers, and bundles repair and maintenance services along with the product and they find the optimal pricing during the product's lifecycle and the optimal leasing duration. This stream of literature does not take competition into account.

In the IT literature, there are a number of studies that show that installed base management introduces positive network externalities that help in creating industry standards owing to compatibility after an innovation (Cheng & Tang, 2010; Farrell & Saloner, 1986; Xie & Sirbu, 1995). These effects have been empirically tested in various industries such as software

(Brynjolfsson & Kemerer, 1996) and video games (Shankar & Bayus, 2003). Schilling (2002) provides an overview of the literature in this field and finds that the firm's learning orientation and timing of entry also affects its ability to define the dominant design, in addition to the installed base. Focused on the video game industry, Chao and Derdenger (2013) analyze mixed bundling in two-sided markets where installed base effects are present and that the pricing structure deviates from traditional bundling as well as the standard two-sided markets literature. In this paper, we consider installed base management for commoditized hardware products primarily, where technological compatibility and network externalities are less likely to drive the installed base policies, hence, we do not take network externalities into account. We make this assumption to keep the model tractable, and it can be relaxed easily.

In this paper we seek an answer to the following question: when is the installed base management policy more profitable than selling? We compare the two policies in monopolistic and competitive environments with firms choosing either identical products or differentiated products. We find that while the selling policy is better in a monopolistic environment, the installed base policy is better in a competitive environment. The remainder of the paper is organized as follows: Section 2 is devoted to the conceptualization of the model and Section 3 to the model results under the assumption of a monopolistic environment. Section 4 introduces the competitive models with identical and differentiated products. We outline the contributions and limitations of this work in Section 5 and provide possible directions for future research.

We now describe the model formulation and solution in detail.

## 2. Model description

To model the demand functions for the cases of installed base management and selling, we assume for the sake of tractability that consumers have linear utility functions. Consider a consumer who wants to either buy or use a durable product, such as a copier or a PC. We model that the consumer will choose the option that provides him with the highest surplus, which is given by the difference between the utility of the product and either the price paid when the consumer purchases the product and the expected service cost in the selling model, or the rent in the installed base management model. The utility derived from the product is modeled by the usage frequency of the product. For a given product, this model is appropriate as consumers are not distinguishing between different products, but rather choosing the mode of use of the product e.g., consumers want copies of documents from a copier, or want to use a medium-sized car, and can either purchase or lease the copier or the car. Hence, the more often they use the car or the copier, the higher the utility. Note that the model of utility used here is different from the model of instantaneous utility used in the literature (for example, a video rental provides utility instantaneously, hence the utility is zero after the product or service is consumed). In this paper, we model the utility of products like copiers and PCs that provide utility a multiple number of times based on usage.

The difference between the selling and installed base mechanisms is in the contractual structure offered by the firm. If the consumer chooses the installed base mechanism offered by the firm, the firm effectively leases the product to the consumer, and the ownership of the product rests with the firm. The consumer then leases the product along with the servicing contract, and is a part of the installed base population. Based on our observations in the industry, the firm offers the installed base option to the consumer as an all-inclusive contract, i.e., the consumer pays a fixed rental price for the usage of the product during the time horizon, with the added utility that he will have the product serviced whenever and as often as needed. In our model, the frequency of breakdown and repair is proportional to the usage frequency of the product. Thus the more often the durable product is used, the more likely it is that it will break down. This assumption is intuitive for all durable products. However, there are cases in which products break down if they have not been used for a long period of time. Hence, we also assume that the usage of the product is uniform during the period, which is not a strong assumption. Hence, consumers with a high usage frequency will prefer to lease the product and be a part of the installed base, as they anticipate that they are more likely to need the service.

If the consumer prefers the selling mechanism, he purchases the product along with a servicing contract from the firm, the servicing contract is based on the usage frequency of the consumer. The selling and servicing contract works as follows: the consumer pays the firm an upfront price for the product, and the ownership of the product is transferred to the consumer. If the consumer uses the product up to a threshold value of usage frequency, the firm services the product for free. If the consumer uses the product with a higher frequency than the threshold value, the firm charges the consumer a variable tariff for the excess usage beyond the threshold (Tucker, 2007). As we show in Section 3.1.3, consumers with a high usage frequency will lease the product while consumers with medium usage frequency will prefer to purchase the product since it is unlikely that they are going to need service often and they are not willing to pay a premium rental price. Finally, consumers with very low valuations will neither purchase nor lease products, as the rent in the installed base model or the price in the selling model will be too high for their surplus to be positive. While every consumer knows how often he might use the product, the manufacturer does not. She cannot perfectly discriminate among consumers based on their usage and service requirements. However, we assume that she knows the distribution of the usage frequencies of the entire set of consumers. We note that, the manufacturer can potentially lease the product by the frequency of usage e.g., mileage on cars, number of copies on copiers, or the number of times a movie in DVD format is watched during the leasing period. However, in most real life scenarios, the rent is fixed on a per period basis.

Based on these observations, we now introduce some notation and assumptions.

**Notation and assumptions**

1. The utility that consumers derive from using the product depends on the frequency with which they use the product. Let $v$ be the frequency of usage per period. We assume that across the entire set of consumers $v$ is uniformly distributed and normalized between 0 and 1 ($v \sim U[0,1]$), with 1 being the highest frequency possible (the manufacturer knows this distribution of frequency of usage). The assumption of uniformly distributed consumers is common in the literature and allows for tractability. We assume that $v$ is also the per period probability that a consumer with usage frequency $v$ will need service. Thus the more often the product is used, the higher is the probability of a breakdown or a service request from the consumer in every period.
2. While the manufacturer can gain a steady stream of revenues by offering a servicing contract, servicing involves costly operations. Servicing examples, depending on the product, include repair, software installation and upgrades, etc. Let $x$ be the cost of servicing a consumer if a breakdown occurs. A durable used by a consumer with usage $v$ will on expectation need cost of servicing $xv$. We note that, the intuition behind our results will not change if we assume that $x$ increases in a convex way as $v$ increases. A consumer who is part of the installed base will have a utility $v$ per period, and pay a fixed rent per period that

includes servicing. We also assume that the length of the period is much longer than the total turnaround time of maintenance, so we do not consider downtime costs in this model.
3. Let $r$ denote the rent a consumer in the installed base pays per period, $p$ the selling price of the product and $s$ the per unit service price charged by the firm if it uses the selling mechanism. We denote $\Pi_{IB}$ as the profits of the installed base policy and $\Pi_{SE}$ as the profits of the selling policy.
4. We assume that the cost of servicing $x$ and the production cost $c$ are the same for the installed base policy and the selling policy. While the production cost being the same is true by assumption (same product), the cost of servicing is likely to be lower for the installed base management policy, as the manufacturer has better design knowledge of the product. For the sake of comparison, we assume that they are the same. To avoid trivial solutions we also assume that $x + c < 1$ so that there is positive demand.
5. We assume that the benefit of remanufacturing the product is much greater for the installed base policy than the selling policy, as the firm retains the ownership of the product. In our observations in the industry, the remanufacturing of products in the installed base policy is close to 100%, as the ownership of the product rests with the manufacturer. For tractability, we assume that there are no secondary markets available to consumers to extract value from products at the end of the time horizon.

In the following sections, we will examine and compare the policies of installed base management in monopolistic and competitive environments.

## 3. Model formulation and analysis

In this section, we compare the policies of installed base management and selling in a two-period horizon, with the selling contract and installed base management contract only being offered at the beginning of the first period. It is well-known that intertemporal utility maximization favors the installed base management model over the selling model, we want to focus on short term horizons.

### 3.1. Installed base management vs selling in monopoly

In the monopoly framework, we consider a manufacturer who uses (i) installed base management only, (ii) selling only, and (iii) a combination of installed base management and selling. Finally, we also analyze a duopoly where one party uses installed base management only and the other party uses selling only.

#### 3.1.1. Installed base management

A consumer with utility $v = v_r$ in each period will be part of the installed base only if he has a positive surplus from leasing the product which implies that $(1+\delta)(v_r - r) \geq 0$. Thus the marginal consumer has utility $v_r = r$. Since the firm retains the ownership of the product, let the value to the firm from remanufacturing the product at the end of the first period be $V$, for durable commoditized products, the remanufacturing savings $V$ models the benefit of the installed base policy, the higher the volume of consumers in the installed base, the higher the value to the manufacturer from the remanufacturing savings. A high value of $V$ will also be passed on to the consumer by a lower rent, $r$. A manufacturer that follows the installed base management policy faces the following maximization problem:

$$\max_r \Pi_{IB} = (1 - v_r)\{(1+\delta)r - c\} - x(1+\delta)\int_{v_r}^{1} y\,dy + \delta(1 - v_r)V$$
$$s.t. \quad v_r = r \tag{1}$$

The term $x\int_{v_r}^{1} y\,dy$ denotes the cost of servicing the portion $[v_r, 1]$ of the market. The total cost of servicing is found by integrating the cost of servicing over the continuum of consumers with utilities that range from $[v_r, 1]$. Also note that the expected cost of servicing is a non-linear function of the market share that the manufacturer services. To see this, let $m_r = 1 - v_r$ denote the portion of the market that is part of the installed base and notice that $x\int_{v_r}^{1} y\,dy = \frac{x}{2}(1 - v_r^2) = \frac{x}{2}m_r(2 - m_r)$. The optimal rental price and profits are given by the following proposition:

**Proposition 1.** *The optimal $r$ that maximizes problem (1) is given by $r^* = \frac{(1+\delta)+c-\delta V}{(1+\delta)(2-x)}$ and the optimal profits are given by $\Pi_{IB}^* = \frac{[(1+\delta)(1-x)-c+\delta V]^2}{2(1+\delta)(2-x)}$.*

**Proof.** All proofs are in the Appendix. □

Notice that the optimal rental price $r^* = \frac{(1+\delta)+c-\delta V}{(1+\delta)(2-x)}$ increases non-linearly with the cost of servicing $x$. The market share of the installed base under the optimal rental price is $m_r^* = 1 - r^* = \frac{(1+\delta)(1-x)-c+\delta V}{(1+\delta)(2-x)}$, and decreases rapidly as the servicing costs $x$ increase.

#### 3.1.2. Selling

In this case, the firm's contract to consumers is modeled as follows. The firm offers the product to the consumer at a selling price of $p$, and free servicing for the usage of the product up to a maximum frequency of usage of $v_b$, corresponding to the minimum frequency of usage of the adopting consumers (marginal consumer). For a frequency of usage beyond this threshold frequency of $v_b$, the firm charges the consumer a servicing charge of $s$ per unit frequency of usage. It is easy to show that the manufacturer will optimally provide free servicing only for consumers up to the maximum frequency of usage of $v_b$, the frequency of usage of the marginal consumer, as this enables the manufacturer to extract the complete utility surplus of all adopting consumers. The consumer's surplus utility is then modeled as: $(1+\delta)v - p - (1+\delta)s(v - v_b)$. To find the marginal consumer, the consumer whose usage frequency satisfies $(1+\delta)v_b - s(1+\delta)(v_b - v_b) - p = 0$ is indifferent between purchasing or not purchasing the product. The manufacturer's problem is:

$$\max_{p,s} \Pi_{SE} = \max_{p,s} \Pi_{SE} = (1 - v_b)(p - c)$$
$$+(1+\delta)\left\{s\int_{v_b}^{1}(y - v_b)dy - x\int_{v_b}^{1} y\,dy\right\}$$
$$s.t. \; v_b(1+\delta) - p = 0 \tag{2}$$

The optimal values of $p$, $s$, and $\Pi_{SE}$ are given by the following proposition:

**Proposition 2.** *The optimal parameters that maximize problem (2) are given by $p^* = \frac{c}{1-x}$, $s^* = 1$, and $v_b = \frac{p^*}{(1+\delta)}$. The optimal profits are given by $\Pi_{SE}^* = \frac{[(1+\delta)(1-x)-c]^2}{2(1-x)(1+\delta)}$.*

Note that if we compare the profits of selling only with those of installed base given by Propositions (1) and (2) respectively, we can see trivially that $\Pi_{SE} \geq \Pi_{IB}$ if the salvage value of the product due to remanufacturing is low, while the reverse is true if the salvage value of the product due to remanufacturing is high. The property of selling dominating installed base management is not an artifact caused by the uniform distribution of usage frequency, the property follows from the fact that the seller uses a two-part tariff, as it charges a price as well as a servicing charge from the consumer, while the installed base policy uses a one-part tariff (absorbing the servicing costs and the rent for using the product in a single payment $r$). The property of selling dominating installed base management in a single-period formulation also holds when there is a salvage value of the product at the end of the period, which is obtained by selling the product to secondary markets. The introduction of secondary markets for the selling case will move it closer to the installed base management case in terms of obtaining the benefits of the salvage value. The case in which the consumer purchases the product in the first period and then sells it in the secondary market in the beginning of the second period is similar to leasing, as the consumer pays a rent of the difference between the price of purchase and the salvage value at the end of the first period. Also note that since the optimal servicing charge is given by $s^* = 1,$ the manufacturer can extract all the surplus utility from consumers using the two-part tariff, while she has to leave some surplus to consumers if she uses the installed base policy.

*3.1.3. Installed base management and selling in a monopoly*

In this subsection, it is assumed that the manufacturer uses both the installed base and selling policies simultaneously. Note that the utility of the consumer from the installed base policy with a frequency of usage of $v$ is given by: $U(IB) = (1+\delta)(v-r)$ and the corresponding utility of the consumer from the selling policy is given by: $U(S) = (1+\delta)v - p - s(1+\delta)(v - v_b)$. For consumers to prefer the installed base policy over the selling policy, $U(IB) > U(S)$ implies that $v > v_b + \frac{(1+\delta)r-p}{s(1+\delta)}$.

Hence, consumers with a high frequency of usage will adopt the installed base policy, and consumers with lower frequency of usage will buy the product. We now find the respective market shares of the selling and installed base policies. Let $v_r$ be the valuation of the marginal consumer who is indifferent between purchasing the product and being in the installed base, and let $v_b$ be the valuation of the marginal consumer who is indifferent between purchasing or not purchasing the product. Then, for the consumer with a usage frequency of $v_r,$ $(1+\delta)(v_r - r) = (1+\delta)v_r - p - s(1+\delta)(v_r - v_b)$. Thus the consumer with a usage frequency of $v_r = v_b + \frac{r - \frac{p}{1+\delta}}{s}$ will be indifferent between buying and leasing the product. On the other hand, if $v_b$ is the valuation of the marginal consumer who is indifferent between purchasing or not purchasing the product, then $(1+\delta)v_b - p - s(1+\delta)(v_b - v_b) = 0$ or $v_b = \frac{p}{1+\delta}$. Thus the market is divided as follows: consumers with usage frequencies ranging from $[v_b + \frac{r-v_b}{s}, 1]$ will be part of the installed base; consumers with usage frequencies ranging from $[\frac{p}{1+\delta}, v_b + \frac{r-v_b}{s}]$ will purchase the product; consumers with usage frequencies ranging from $[0, \frac{p}{1+\delta}]$ will not use the product at all. It is important to note that more than half of the firms that have a copier in-house prefer to lease them with an installed base contract covering the maintenance compared to purchasing them (CBS, 2014), for high frequency users, the advantages of having the maintenance included in the contract lowers the payments on maintenance. Users with lower frequency of usage may not need maintenance as frequently, hence, they prefer to purchase the copier and pay for the maintenance as and when required by adopting the selling mechanism. Altman and Chu (2001) and Balasubramanian, Bhattacharya, and Krishnan (2015) also find that consumers with high frequency of usage prefer a flat fee pricing structure, while consumers with low frequency of usage prefer a pay-as-you-go mechanism for pricing. However, in practice, customers with very high usage frequencies may sometimes prefer to have either an in house maintenance staff or have a contract with a third party to maintain the product if the time of repair is of critical importance, we do not consider factors other than maintenance cost in the paper. The manufacturer's maximization problem is:

$$\max_{r,p} \Pi_{IB\ and\ SE} = (1-v_r)\{(1+\delta)r - c\} - (1+\delta)x\int_{v_r}^{1} y dy + \delta(1-v_r)V \quad (3)$$

$$+(v_r - v_b)(p-c) + (1+\delta)\left\{s\int_{v_b}^{v_r}(v - v_b)dv - x\int_{v_b}^{v_r} v dv\right\}$$

$$s.t.\ v_r = \frac{p}{1+\delta} + \frac{r - \frac{p}{1+\delta}}{s} \quad \text{and} \quad v_b = \frac{p}{1+\delta} \quad (4)$$

The optimal values of $r,\ p, s, v_r, v_b$ and the optimal profits for problem (3) are given by the following proposition:

**Proposition 3.** *The solution to problem (3) is*

$$r^* = 1 - \frac{\delta V}{1+\delta} \quad \text{and} \quad p^* = \frac{c}{1-x} \quad \text{and} \quad s = 1$$

$$v_r^* = 1 - \frac{\delta V}{1+\delta} \quad \text{and} \quad v_b^* = \frac{c}{(1+\delta)(1-x)}$$

*The optimal profits are given by* $\Pi^*_{IB\ and\ SE} = \frac{[(1+\delta)(1-x)-c-\delta V(1-x)]^2}{2(1-x)(1+\delta)} + \frac{\delta V}{1+\delta}\{1+\delta-c-x+\frac{\delta V x}{2(1+\delta)}\}$.

Proposition (3) states that it is always optimal for a manufacturer to choose a mixed strategy of installed base management and selling if the product has a positive value at the end of the first period due to remanufacturing savings, and to use a selling strategy only if this value $V$ is equal to zero. The intuition behind Proposition (3) is as follows: when the manufacturer uses the installed base policy, she internalizes the cost of providing maintenance services to the consumer, and hence charges a higher rent. Consequently, the constraint of providing the maintenance service reduces the market share of the manufacturer. In contrast, if she sells the product, she extracts the entire surplus utility of the consumer, by using the maximum value possible for the servicing charge, and hence, she charges a lower selling price, and has a higher market share. Therefore, using both strategies together is the optimal policy. Propositions (1)–(3) show that in a monopolistic environment, the optimal strategy for a manufacturer is to follow the selling strategy if the salvage value of the product from the installed base policy at the end of the life-cycle is zero, and use both strategies in tandem if the product has a positive salvage value. The intuition comes from the fact that a manufacturer who follows the installed base management policy faces a lower market share to account for servicing.

## 4. Installed base management and selling in a competitive environment

In this section, we compare the use of installed base management and selling in a duopoly. In the first section, we assume that both firms offer identical products, (i.e., both products are vertically undifferentiated), while in the next section, we assume that both firms offer vertically differentiated products (the utility from using one firm's product is $A$ times the utility of the other, $A > 1$).

*4.1. Competition between firms using vertically undifferentiated products*

Consider a duopoly between two firms with both firms offering the same product to consumers with potentially different mechanisms (installed base management and selling only, or any combination of the two). The firms first choose their mechanism(s) of offering the durable good, followed by the respective rents, selling prices and service charges in the second stage (see Coughlan, 1985 for similar two-stage games) with one firm following the installed base management policy and the other following the selling policy (both firms follow pure strategies). We first show that no Nash equilibrium exists when the two firms either use the same mechanism or both mechanisms (see Result 1 in the Appendix). If both firms employ the same mechanism, they compete in a Bertrand fashion on the basis of prices only, and there exists no Bertrand equilibrium for firms offering identical products with the same mechanism that are differentiated on the basis of prices only. Each firm finds it optimal to lower its price to get the entire market share, leading the game to have a no Nash equilibrium with positive profits for both firms. The firms can only have a Nash equilibrium outcome when they employ different mechanisms as the different prices charged under the different mechanisms enables them to move away from the Bertrand competition model. Let $v_r$ be the usage frequency of the consumer who is indifferent between being a member of the installed base and purchasing the product. Then, as in the monopoly case, we have $(1+\delta)(v_r - r) = (1+\delta)v_r - p - s(1+\delta)(v_r - v_b)$, yielding $v_r = v_b + \frac{r - v_b}{s}$. For the marginal consumer in the selling case, we have $(1+\delta)v_b - p - s(1+\delta)(v_b - v_b) = 0$ or $v_b = \frac{p}{1+\delta}$. We assume that the two firms engage in price competition, hence they simultaneously maximize their profits. The competition problem in pure strategies is given by:

$$\max_r \Pi_{IB} = (1 - v_r)\{(1+\delta)r - c\} - (1+\delta)x\int_{v_r}^{1} y dy + \delta(1 - v_r)V$$

$$\max_{p,s} \Pi_{SE} = (v_r - v_b)(p - c) + (1+\delta)\left\{s\int_{v_b}^{v_r}(v - v_b)dv - x\int_{v_b}^{v_r} v dv\right\}$$

$$s.t.\ v_r = \frac{p}{1+\delta} + \frac{r - \frac{p}{1+\delta}}{s} \quad \text{and} \quad v_b = \frac{p}{1+\delta} \tag{5}$$

The optimal $r, p, \Pi_{IB}, \Pi_{SE}$ are given by the following proposition:

**Proposition 4.** *The solution is based on the value of the servicing cost x, and is given by:*

*Case 1: If* $\frac{1}{2} \le x \le 1 - c$, *then the Nash equilibrium values of the rent, selling price and servicing charge set by the two firms are given by:* $r^* = \frac{(1+\delta)+c-\delta V}{(1+\delta)(2-x)}$, $p^* = \frac{c}{(1-x)}$, $s^* = 1$. *The equilibrium profits are given by:* $\Pi_{IB}^* = \frac{[(1+\delta)(1-x)-c+\delta V]^2}{2(1+\delta)(2-x)}$, $\Pi_{SE}^* = \frac{[(1+\delta)(1-x)-c-\delta V(1-x)]^2}{2(1+\delta)(1-x)(2-x)^2}$. *The firm offering the installed base policy has the same profits as in the case when it offered the installed base option alone in a monopoly, whereas the firm using the selling policy has lower profits than if it used the selling policy alone in a monopoly.*

*Case 2: If* $x < \frac{1}{2}$, *then in equilibrium, the selling firm sets* $s^* = 0$, *and* $p^* = \frac{2c+x(1+\delta)}{(2-x)}$. *The firm offering the installed base policy sets* $r^* = \frac{2c+x(1+\delta)}{(1+\delta)(2-x)} - \epsilon$, $\epsilon \to 0$. *The equilibrium profits are given by:* $\Pi_{IB}^* = \frac{[2(1+\delta)(1-x)-c]\delta V}{(1+\delta)(2-x)}$, $\Pi_{SE}^* = 0$.

From Proposition (4), we see that if the cost of servicing is high, then the selling firm extracts all the surplus utility of consumers in equilibrium, however, this strategy gives the selling firm a smaller share of the profits, as consumers with higher usage frequencies prefer to use the installed base option, which leaves consumers with some surplus utility. As the selling firm's market share consists of those consumers with medium usage frequencies ($0 < v_b < v_r$), she does not have high profits in equilibrium. In contrast, the firm using the installed base policy has its market share among consumers with high usage frequencies, hence, in equilibrium, the firm using the installed base policy does better than the selling firm.

If the servicing cost is low, the firm choosing the selling policy in equilibrium chooses not to extract the surplus utility from the consumer as in the monopoly cases. The firm using the selling option now has an incentive to lower the servicing charge $s$, as lowering $s$ increases her market share. In the Nash equilibrium, both

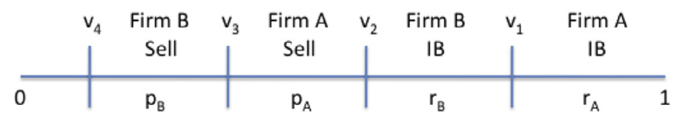


**Fig. 1.** Market shares for firms A and B for low values of *A*.

firms offer a higher utility surplus for the consumer compared to the monopoly cases. While this is intuitive and in consonance with the literature (consumers get a higher utility surplus in competitive markets than in monopolistic markets), it is interesting to note that the lower service charge results in a reduced degree of differentiation of the selling and installed base mechanisms ($s = 0$ implies that both firms use a single tariff structure). This lower degree of differentiation results in both firms competing on cost in equilibrium, and the firm offering the installed base policy can offer a lower rent to the consumer owing to the remanufacturing savings $V$, hence, the profits for the firm offering the installed base policy are increasing in $V$. The intuition behind this result is as follows: the selling option is dominant in the monopoly setting as the firm can extract all the consumer surplus with the servicing charge. However, in the duopoly, the firm offering the selling option is constrained by a lower market share (the firm offering the installed base option offers consumers a positive utility surplus), hence, the firm offering the selling option has to offer consumers a higher utility surplus as well, resulting in a lower servicing charge and profits.

**Proposition 5.** *Let the profit of the selling firm in the pure strategy equilibrium be* $\Pi_{SE}$ *and the profit of the firm using the installed base mechanism be* $\Pi_{IB}$. *In the competitive game with vertically undifferentiated goods, there also exists a symmetric mixed-strategy Nash equilibrium, where each firm chooses the selling mechanism with a probability of* $\sigma_{SE} = \frac{\Pi_{SE}}{\Pi_{SE}+\Pi_{IB}}$ *and the installed base mechanism with a probability of* $\sigma_{IB} = \frac{\Pi_{IB}}{\Pi_{SE}+\Pi_{IB}}$.

The existence of the mixed-strategy model is based on the existence of pure strategies which are differentiated (Dixit & Shapiro, 1986) in the classic "Battle of the Sexes" Game. In the mixed-strategy outcome, the probability that both firms will eventually have different pure strategies is given by $2\sigma_{SE}(1 - \sigma_{SE})$. The obvious shortcoming of the mixed-strategy equilibrium is that firms are not able to guess a priori the mechanism that will be used by the competitor, but that problem exists even if both firms do not signal to each other their intended mechanism at the start of the pure strategy game.

### *4.2. Competition between two firms using vertically differentiated products*

Consider two firms (labelled as A and B) that use both the options of installed base management and selling in a competitive environment. It trivially follows that no non-zero price Nash equilibrium can exist if both firms offer the same product, as the firms will continue to undercut the other's price. Hence, we assume that firm A offers a better product than firm B, and model the utility from firm A's product as $Av$ ($A > 1$). This assumption can be interpreted as the consumer getting a utility of $A$ times the utility from firm A's product compared to firm B's product for each use. We denote the selling price, rent per period and servicing charges of firms A and B as $p_A$, $r_A$, $s_A$ and $p_B$, $r_B$, $s_B$ respectively. We find that there are two resultant market structures possible. If the value of $A$ is low (slightly above 1), the market shares of the two firms from the two different options each are depicted in Fig. 1. If the value of $A$ is significantly higher than one, then the market shares of

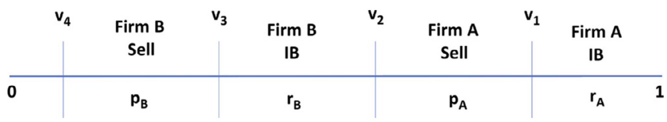


**Fig. 2.** Market shares for firms A and B for high values of $A$.

the two firms from the two different options each are depicted in Fig. 2.

In Fig. 1, the frequency of usage of the marginal consumers $v_4$, $v_3$, $v_2$ and $v_1$ are found by setting the utilities from the two neighboring options to be equal. Hence,

$(1+\delta)v_4 - p_B - s_B(1+\delta)(v_4 - v_4) = 0 \Longrightarrow v_4 = \frac{p_B}{1+\delta}$

$(1+\delta)Av_3 - p_A - s_A(1+\delta)(v_3 - v_3) = (1+\delta)v_3 - p_B - s_B(1+\delta)(v_3 - v_4) \Longrightarrow v_3 = \frac{p_A - p_B + s_B(1+\delta)v_4}{(1+\delta)(A+s_B-1)}$

$(1+\delta)v_2 - (1+\delta)r_B = (1+\delta)Av_2 - p_A - s_A(1+\delta)(v_2 - v_3) \Longrightarrow v_2 = \frac{(1+\delta)r_B - p_A + s_A(1+\delta)v_3}{(1+\delta)(-A+s_A+1)}$

$(1+\delta)Av_1 - (1+\delta)r_A = (1+\delta)v_1 - (1+\delta)r_B \Longrightarrow v_1 = \frac{r_A - r_B}{A-1}$

The profits for firms A and B are given as follows:

$\max_{p_A, r_A, s_A} \Pi_A = (1 - v_1)\{(1+\delta)r_A - c\} - (1+\delta)x\int_{v_1}^{1} y dy + \delta(1 - v_1)V + (v_2 - v_3)(p_A - c) + (1+\delta)\{s_A \int_{v_3}^{v_2}(v - v_3)dv - x\int_{v_3}^{v_2} v dv\}$

$\max_{p_B, r_B, s_B} \Pi_B = (v_1 - v_2)\{(1+\delta)r_B - c\} - (1+\delta)x\int_{v_2}^{v_1} y dy + \delta(v_1 - v_2)V + (v_3 - v_4)(p_B - c) + (1+\delta)\{s_B \int_{v_4}^{v_3}(v - v_4)dv - x\int_{v_4}^{v_3} v dv\}$

The values of $v_1$, $v_2$, $v_3$ and $v_4$ and the corresponding profits for the market structure in Fig. 2 can be characterized analogously, and the characterizations are omitted for brevity. This problem is not analytically tractable, hence, we solve for the optimal values of $p_A$, $r_A$, $s_A$ and $p_B$, $r_B$, $s_B$ numerically. We conducted sensitivity analysis for the equilibrium outcomes for $x$ and $A$ (in all the numerical solutions for varying $x$, we use the following values of $A$, $\delta$, $c$, and $V$: $A = [1.4, 1.8]$, $\delta = 0.95$, $c = 0.3$, $V = 0.1$). The results are summarized below.

Case 1: $x < 0.5$. When the value of the servicing cost $x$ is small, we observe that both firms prefer not to use the servicing charge in the selling policy ($s_A$, $s_B \approx 0$), hence, both firms prefer to compete using the installed base option only. Note that in the absence of the servicing charge $s$, the installed base management and selling options converge to the same option (using a single payment tariff). The intuition behind these results is similar to the case obtained above, in the pure strategy case. When the value of $x$ is small, both firms find that they optimize their profits by not using a servicing charge, and gaining a higher market share using the installed base policy only. As the value of $x$ increases, firm B finds it optimal to keep its servicing charge at 0, while firm A charges a nominally higher value of servicing charge, the bulk of the profits and market share of firms A and B still come from the installed base policy. The findings are summarized in Fig. 3(a).

Case 2: $0.5 < x < 1$. When the value of the servicing cost $x$ is large, we observe that both firms use both the installed base and selling policies in tandem in a competitive environment. Similar to the case of the competition with pure strategies described above, firm A charges a high servicing charge, and extracts most of the surplus utility from consumers who buy its product. In contrast, firm B charges a lower servicing charge, as it finds it better in this case in equilibrium to have a higher market share from selling its product compared to the case when $x$ is low. Both firms get a higher share of their profits from using the installed base policy in this case as well compared to the selling policy. The findings are summarized in Fig. 3(b).

When the value of $A$ increases (firm A's product is significantly better than firm B's product), as expected, we find that the market structure switches to Fig. 2. The intuition behind the switch is as follows. When the value of $A$ is low (slightly higher than 1), consumers with a higher frequency of usage prefer to use the installed base mechanism from firm B in preference to buying the product from firm A. The intuition behind the preference is that in this region, the additional servicing and maintenance cost from the selling contract of firm B is higher, and overcomes the additional utility of the $Av$ factor ($A > 1$) from buying the product of firm A. As the value of $A$ goes higher, the additional utility of buying the product from firm A with a utility of $Av$ gets to be higher for consumers with higher frequency, overshadowing the additional cost of servicing and maintenance of the product, and consumers with a higher frequency prefer to purchase the product from firm A. The findings are summarized in Fig. 4.

However, even though both firms use both mechanisms in these cases, in both cases, the firms earn higher profits from the installed base management mechanism in contrast to the selling mechanism, as consumers with the higher frequency of usage prefer to

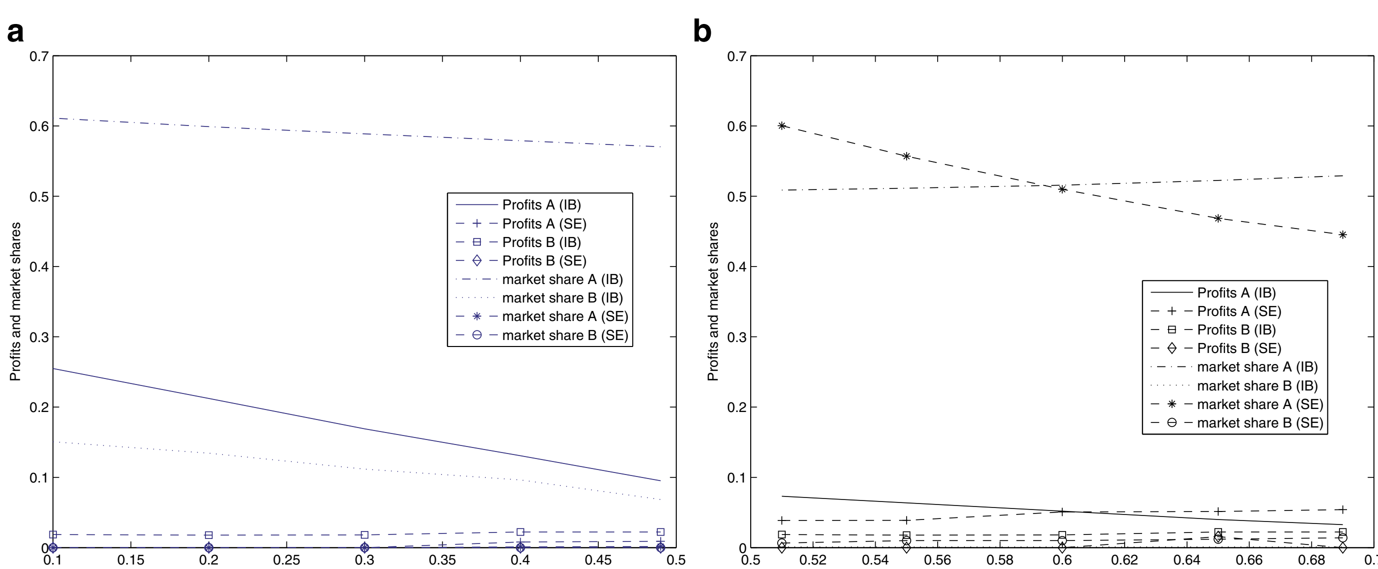


**Fig. 3.** Profits for firms A and B for (a) $x < 0.5$, $A = 1.4$, $c = 0.3$, $\delta = 0.95$, $V = 0.1$ and (b) $x > 0.5$, $A = 1.4$, $c = 0.3$, $\delta = 0.95$, $V = 0.1$.

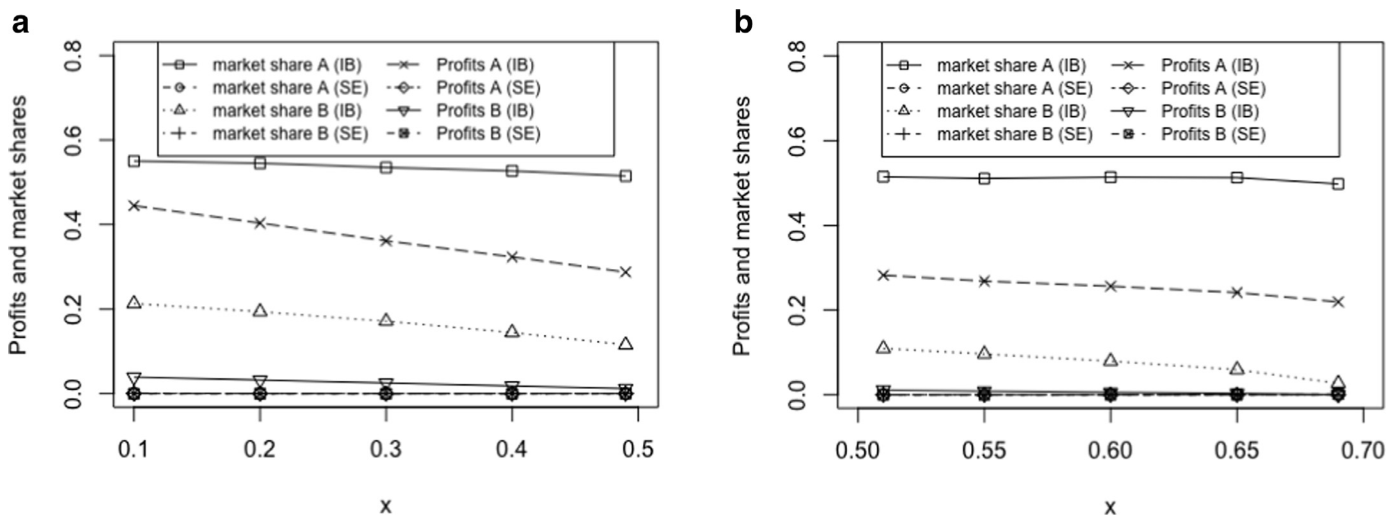


**Fig. 4.** Profits for firms A and B for (a) $x < 0.5$, $A = 1.8$, $c = 0.3$, $\delta = 0.95$, $V = 0.1$ and (b) $x > 0.5$, $A = 1.8$, $c = 0.3$, $\delta = 0.95$, $V = 0.1$.

use the installed base mechanism. Hence, the intuition behind our results does not change.

We now summarize the results of the paper, and outline directions for future research.

## 5. Conclusions and directions for future research

Using the policy of installed base management against selling has important ramifications for the firm's profits. The contribution of this paper to the literature is a model that studies the benefits of retaining the ownership of the product through leasing in conjunction with providing repair and maintenance services to the consumer. The model incorporates the utility to the consumer based on usage frequency rather than instantaneous consumption, and analyzes the cost of internalizing servicing expenses against the benefit of retaining ownership of the products in monopolistic and competitive environments.

The results of the paper show that for the manufacturer, using the selling policy is better than installed base management in a monopoly, as providing a servicing contract that is separate from the price of the product increases the servicing price charged by the manufacturer. The manufacturer can extract the entire consumer utility surplus even when consumers have heterogeneous frequencies of usage, and the servicing charge acts as a price discriminating tool for the manufacturer. In contrast, in the installed base policy case, the firm internalizes the costs of servicing, and the market share for the manufacturer is also lower, hence, if there is no salvage value of the product at the end of the time horizon, the profits from the installed base option are lower than the profits from the selling option.

If two manufacturers compete with each other and both use identical products, this paper shows that the two firms only have non-zero profits in equilibrium if they use different strategies, and no equilibrium exists if both firms use the same strategy either alone or in a combination with the other strategy. The efficacy of the installed base policy is higher than in the monopoly case, while the efficacy of the selling policy is lower than in the monopoly case. If two firms use differentiated products in a duopoly, they can use both mechanisms in conjunction, but the efficacy of the installed base mechanism is higher than that of the selling mechanism. This owes to the fact that in a competitive environment, the firm using the selling policy has to lower its servicing charge to balance for the consumer utility surplus offered by the installed base policy to gain additional market share. The lowered servicing charge greatly reduces the profit potential of the selling option, hence, it is not as attractive as it is in a monopoly.

To illustrate the results, copiers are a good case in point, as indeed, Xerox was the first manufacturer to move to a "lease only" policy, by taking advantage of a competitive environment and improvements in servicing technologies (lower $x$). Xerox was also the first manufacturer in their sector to introduce remanufacturing to extract further surpluses from their installed base policy. There are many other examples in other sectors of manufacturers moving to an installed base policy from a selling policy under similar conditions, such as Otis Elevators, HP Servers, and Douwe Egberts coffee machines.

In the early phase of this research, we have made a number of assumptions that should be relaxed in future research. We have assumed that there are no secondary markets. Future research should study the impact of secondary markets on the choice between installed base management and selling. We conjecture that the existence of secondary markets will help selling more, as consumers can effectively get a trade-in value in the secondary market, and purchasing the new product generation will then be more attractive. We have also assumed that there is no setup cost if the manufacturer operates on an installed base policy. Future research should consider the impact of setup costs on the policy decision. We conjecture that the existence of setup costs in the installed base case would require a minimum cutoff number of consumers using the product with a frequency above a certain usage frequency for the manufacturer to operate with an installed base policy. We also assumed that the maintenance costs increase as the frequency of usage increases. Empirical work to test this assumption would be useful to determine the applicability of the model in other sectors than the ones that inspired our assumptions (such as copiers and cars). We also did not take into account design cost aspects in the reduction of the servicing cost or creation of dominant designs using the installed base policy. We also model the installed base policy as a lease payment coupled with an extended warranty that includes all maintenance services, while in the selling option, the maintenance contract is sold separately. The bundling of the maintenance service with the leasing is an important aspect driving the results of the paper. We also did not take into account design cost aspects in the reduction of the servicing cost or creation of dominant designs using the installed base policy. While the selling and installed base mechanisms were compared from the maintenance contract added on in this paper, we did not account for the impact of complementary products and the potential of upgrades on these mechanisms. Future research should take these factors into account.

In summary, this paper makes a contribution to the literature and practice of installed base management by pointing out the impact of production costs, servicing costs, competition and remanufacturing on the policy choice between installed base management and selling. Our recommendation is that manufacturers make a conscious and proactive policy choice, as our results show that different policies are appropriate in different environments.

## Appendix

**Proof of Proposition (1).** $V$ denotes the salvage value of the product. The problem of the manufacturer if it offers the product using installed base management is given by:

$$\max_r \Pi_{IB} = (1-v_r)\{(1+\delta)r - c\} - x(1+\delta)\int_{v_r}^{1} y dy + \delta(1-v_r)V$$
$$s.t. \quad v_r = r \tag{6}$$

The profits reduce to $\Pi_{IB} = (1-r)\{(1+\delta)(r-(c-\delta V))\} - \frac{x}{2}(1+\delta)(1-r^2)$. The first order condition (FOC) with respect to $r$ gives $-2(1+\delta)r + (1+\delta) + c - \delta V + (1+\delta)rx = 0$, hence, $r^* = \frac{(1+\delta)+c-\delta V}{(1+\delta)(2-x)}$. Substituting $r^*$ back into $\Pi_{IB}$ gives $\Pi^*_{IB} = \frac{[(1+\delta)(1-x)-c+\delta V]^2}{2(1+\delta)(2-x)}$. □

**Proof of Proposition (2).** If the manufacturer uses the selling policy, the consumer who is indifferent between purchasing or not purchasing the product has utility $v_b$ such that $v_b(1+\delta) - p + s(1+\delta)(v_b - v_b) = 0$ , or $v_b = \frac{p}{(1+\delta)}$. The problem of the manufacturer is given by

$$\max_{p,s} \Pi_{SE} = (1-v_b)(p-c) + (1+\delta)\left\{ s\int_{v_b}^{1}(y-v_b)dy - x\int_{v_b}^{1} y dy \right\} \tag{7}$$

$$s.t.\ v_b(1+\delta) - p = 0$$

The profit function reduces to $\Pi_{SE} = (1-\frac{p}{1+\delta})(p-c) + (1+\delta)\{s\frac{(1-v_b)^2}{2} - x\frac{1-v_b{}^2}{2}\}$

$= (1-\frac{p}{1+\delta})[(p-c) + (1+\delta)\{s\frac{1-v_b}{2} - x\frac{1+v_b}{2}\}]$.

It is trivial to see that $s^* = 1$, as the derivative of the profit function w.r.t $s$ is strictly increasing.

The first order condition (FOC) with respect to $p$ gives

$(1-\frac{p}{1+\delta})\{1-\frac{1}{2}-\frac{x}{2}\} - \frac{1}{1+\delta}[(p-c) + (1+\delta)\{\frac{1-v_b}{2} - x\frac{1+v_b}{2}\}] = 0$.

$\implies p* = \frac{c}{1-x}$.

Substituting $p^*$ back into $\Pi_{SE}$ gives $\Pi^*_{SE} = \frac{[(1+\delta)(1-x)-c]^2}{2(1+\delta)(1-x)}$.□

**Proof of Proposition (3).** If the monopolist uses both the installed base and selling policies, her profits are give by $\max_{r,p} \Pi_{IB\ and\ SE} = (1-v_r)\{(1+\delta)r - c\} - (1+\delta)x\int_{v_r}^{1} y dy + \delta(1-v_r)V + (v_r - v_b)(p-c) + (1+\delta)\{s\int_{v_b}^{v_r}(v-v_b)dv - x\int_{v_b}^{v_r} v dv\}$, where $v_r$ is given by the equation $v_r = v_b + \frac{r-v_b}{s}$ and $v_b = \frac{p}{1+\delta}$. The FOC of the above profit function are given by:

$\frac{\partial \Pi_{IB\ and\ SE}}{\partial s} = (1-v_r)(1+\delta)\frac{x}{2}\frac{r-v_b}{s^2} + \frac{r-v_b}{s^2}[(1+\delta)r - c + \delta V(1+\delta)\frac{x}{2} - (1+\delta)\frac{x}{2}v_r - p + c - (1+\delta)\frac{s}{2}(v_r - v_b) + (1+\delta)\frac{x}{2}(v_r + v_b) + (1+\delta)\frac{x}{2}(v_r - v_b)]$.

After simplification, this reduces to $\frac{\partial \Pi_{IB\ and\ SE}}{\partial s} = \frac{r-v_b}{s^2}[(1+\delta)\frac{r}{2} - \frac{p}{2} + \delta V]$. 0 as $r > p$ and $V > 0$. Hence, $s^* = 1$.

The FOC for $r$ and $p$ are:$(1+\delta) - (1+\delta)\frac{r}{s} - \frac{\delta V}{s} - p + \frac{p}{s} = 0$.

Substituting the value of $s^* = 1$ in the above FOC yields the desired results. The profits are found by substituting the optimal parameters in the profit function. □

**Table 1**
Nash equilibrium outcomes when firms can use either or both mechanisms.

| | | Firm 1 | | |
|---|---|---|---|---|
| | | Selling | IBM | Both |
| **Firm 2** | **Selling** | No equilibrium | Equilibrium exists | No equilibrium |
| | **IBM** | Equilibrium exists | No equilibrium | No equilibrium |
| | **Both** | No equilibrium | No equilibrium | No equilibrium |

**Result 1**: *There exists no Nash equilibrium with the two firms having positive profits if both of them employ the same mechanism either alone or in conjunction with the other mechanism.*

**Proof of Result 1.** Table 1 below summarizes the possible strategies used by both parties in equilibrium. □

**Case 1: Firm 1 uses only selling, Firm 2 uses only installed base mechanism**

Consider a duopoly where firm 1 only uses the selling mechanism, and firm 2 only uses the installed base mechanism to offer the durable good. The selling price charged by the selling firm 1 is denoted as $p$ and the service charge per period is denoted as $s$. The rent charged by the firm using the installed base policy is denoted as $r$. Hence, the utility to the consumer from selling is $U_S(p,s) = (1+\delta)v - p - (1+\delta)s(v-v_b)$ and $U_{IB}(r) = (1+\delta)(v-r)$. The marginal consumer between the selling and installed base policies is characterized by the frequency of usage where these utilities are equal and denoted by $v_r$: $v_r = v_b + \frac{r-v_b}{s}$. Setting the utility of the consumer to 0 gives us the marginal consumer who buys the product: $v_b = \frac{p}{1+\delta}$. The expressions for the market shares of the selling and installed base mechanisms are $v_r - v_b$ and $1-v_r$ respectively.

The competing firms maximize their individual profits:

$$\max_r \Pi_{IB} = (1-v_r)\{(1+\delta)r - c\}$$
$$-(1+\delta)x\int_{v_r}^{1} y dy + \delta(1-v_r)V \tag{8}$$

$$\max_{p,s} \Pi_{SE} = (v_r - v_b)(p-c)$$
$$+(1+\delta)\left\{ s\int_{v_b}^{v_r}(v-v_b)dv - x\int_{v_b}^{v_r} v dv \right\}$$
$$s.t.\ v_r = \frac{p}{1+\delta} + \frac{r - \frac{p}{1+\delta}}{s} \quad \text{and} \quad v_b = \frac{p}{1+\delta}$$

To see that this game yields a unique asymmetric Nash equilibrium, it is sufficient to check the SOC (second-order conditions) are satisfied at the Nash equilibrium. It can be easily seen that the SOC for $\Pi_{IB}$ with respect to $r$ and the SOC for $\Pi_S$ with respect to $p$ and $s$ are satisfied.

**Case 2: Firm 1 uses only selling, Firm 2 uses only selling**

If the firms each only use the selling mechanism, let the selling price charged by firm 1 be denoted by $p_1$ and the selling price of firm 2 be denoted by $p_2$. Let the service charges of the two firms be denoted by $S_1$ and $S_2$. Let the profits of firm 1 be denoted by $\Pi_{S1}(p_1, p_2, s_1, s_2)$ and the profits of firm 2 be denoted by $\Pi_{S2}((p_1, p_2, s_1, s_2))$. Hence, $U(S_1) = (1+\delta)v - p_1 - s_1(1+\delta)(v-v_b)$ and $U(S_2) = (1+\delta)v - p_2 - s_2(1+\delta)(v-v_b)$.

It is easy to see that $p_1 > p_2$ and $s_1 > s_2$ cannot be a Nash equilibrium, as in that case $U_{S1} < U_{S2}$ always. The same is true if $p_1 < p_2$ and $s_1 < s_2$. Hence, without loss of generality, we assume that $p_1 > p_2$ and $s_1 < s_2 . U(S_1) > U(S_2)$ implies that $v - v_b > \frac{p_1 - p_2}{(1+\delta)(s_2 - s_1)}$. Hence, if $v_s$ is the marginal consumer between buying products 1 and 2, $v_s = v_b + \frac{p_1 - p_2}{(1+\delta)(s_2 - s_1)}$. The marginal consumer for product 2 is given by $v_b = \frac{p_2}{1+\delta}$ as before, and is obtained by setting

$U(S_2) = 0$. Hence, consumers with a usage frequency from $v_s$ to 1 buy product 1, and consumers with a usage frequency of $v_b$ to $v_s$ purchase product 2.

The profits of the two firms are given as follows:

$$\max_{p_1,s_1} \Pi_1 = (1-v_s)(p_1-c) + (1+\delta)\left\{s_1\int_{v_s}^{1}(v-v_b)dv - x\int_{v_s}^{1} vdv\right\}$$

$$\max_{p_2,s_2} \Pi_2 = (v_s-v_b)(p-c) + (1+\delta)\left\{s_2\int_{v_b}^{v_s}(v-v_b)dv - x\int_{v_b}^{v_s} vdv\right\} \quad (9)$$

The solution to the FOC in the Nash equilibrium is $p_1 = s_1 = p_2 = s_2 = 0$, demonstrating that a Nash equilibrium with non-zero prices and profits does not exist when each firm employs only selling. □

**Case 3: Firm 1 and firm 2 each use only installed base management**

Let the rent charged by firm 1 be denoted by $r_1$ and the rent of firm 2 be denoted by $r_2$. Let the profits of firm 1 be denoted by $\Pi_{IB1}(r_1,\ r_2)$ and the profits of firm 2 be denoted by $\Pi_{IB2}(r_1,\ r_2)$. A necessary condition for the Nash equilibrium (with non-zero profits for both firms) to exist is (here $r_1^*$ and $r_2^*$ are the Nash equilibrium prices):

$$\Pi_{IB1}(r_1^*, r_2^*) > \Pi_{IB1}(r_1^*+\epsilon, r_2^*)$$

and

$$\Pi_{IB1}(r_1^*, r_2^*) > \Pi_{IB1}(r_1^*-\epsilon, r_2^*)$$

$$\Pi_{IB2}(r_1^*, r_2^*) > \Pi_{IB2}(r_1^*, r_2^*+\epsilon)$$

and

$$\Pi_{IB2}(r_1^*, r_2^*) > \Pi_{IB2}(r_1^*, r_2^*-\epsilon)$$

That is, both firms should have no incentive to deviate from the Nash equilibrium prices.

The net surpluses of a consumer who uses the durable good on an installed base from firm 1 and firm 2 are, respectively:

$$U_{IB1}(r_1) = (1+\delta)(v-r_1)$$

$$U_{IB2}(r_2) = (1+\delta)(v-r_2)$$

If the durable good is not vertically differentiated, it is easy to see that if $r_1 \neq r_2$, the entire market share goes to the firm with the lower rent, and the other firm is left with zero profits. This leads to price undercutting, as if $r_1$ is lower than $r_2$ (and vice versa), the entire market share goes to firm 1 (firm 2 respectively). Hence, unequal values of $r_1$ and $r_2$ do not constitute a Nash equilibrium.

Now, let us assume that $(r_1^*, r_2^*)$ is a Nash equilibrium and let $r_1^* = r_2^* = r^*$, where $0 \le r^* \le 1$. Because the net consumer surplus for both firms is equal, we can conclude that the market shares for both firms are equal. Then:

$$\Pi_{IB1}(r1^*, r_2^*) = \frac{(1-r^*)}{2}\{(1+\delta)r-c\} - (1+\delta)x\int_r^1 ydy + \delta(1-r)V$$

and

$$\Pi_{IB2}(r1^*, r_2^*) = \frac{(1-r^*)}{2}\{(1+\delta)r-c\} - (1+\delta)x\int_r^1 ydy + \delta(1-r)V$$

In this case, the conditions $\Pi_{IB1}(r_1^*, r_2^*) > \Pi_{IB1}(r_1^*-\epsilon, r_2^*)$ and $\Pi_{IB2}(r_1^*, r_2^*) > \Pi_{IB2}(r_1^*, r_2^*-\epsilon)$ are not satisfied for all $r^* > 0$. If $\epsilon = \lim_{h\to 0} h$, for firm 1, then:

$$\Pi_{IB1}(r1^* - \lim_{h\to 0} h, r_2^*)$$

$$= (1-r)\{(1+\delta)r-c\} - (1+\delta)x\int_r^1 ydy + \delta(1-r)V$$

$$> \frac{(1-r^*}{2})\{(1+\delta)r-c\} - (1+\delta)x\int_r^1 ydy + \delta(1-r)V$$

A symmetric condition holds for firm 2. Therefore, there is a contradiction and a Nash equilibrium with non-zero prices and profits do not exist when each firm employs only the installed base mechanism. □

The proofs that demonstrate that other mechanism combinations in the duopoly lead to no-equilibrium outcomes follow along similar lines. Those proofs can be obtained from the authors on request.

**Proof of Proposition (4).** In a duopoly, $v_r$ and $v_b$ are given by the equations $v_r = v_b + \frac{r-v_b}{s}$ and $v_b = \frac{p}{1+\delta}$. The firm using the installed base policy has profits of $\Pi_{IB} = (1-v_r)\{(1+\delta)r-c\} - (1+\delta)x\int_{v_r}^1 ydy + \delta(1-v_r)V$

$= (1-v_r)\{(1+\delta)r - c + \delta V - \frac{x}{2}(1+\delta)(1+v_r)\}.$ (A4.1)

The profit of the firm using the selling option is $\Pi_{SE} = (v_r - v_b)(p-c) + (1+\delta)\{s\int_{v_b}^{v_r}(v-v_b)dv - x\int_{v_b}^{v_r} vdv\}.$

$= (v_r-v_b)[p-c+(1+\delta)\frac{s}{2}(v_r-v_b) - (1+\delta)\frac{x}{2}(v_r+v_b)].$ (A4.2)

Note that $\Pi_{IB}$ is quadratic in $r$, and of the form

$\Pi_{IB} = (D-\frac{r}{s})\{Er+K\}.$ where $D = 1+v_b(\frac{1}{s}-1)$, $E = (1+\delta)(1-\frac{x}{2s})$, $K = -c+\delta V - \frac{x}{2}(1+\delta) + \frac{x}{2}(1+\delta)v_b(\frac{1}{s}-1)$

The equilibrium reaction function $r$ from the FOC is then given by:

$r^* = \frac{sDE-K}{2E}$

$\Rightarrow r^* = \frac{s(1+\delta)+p(1-s)+c-\delta V-px(\frac{1}{s}-1)}{(1+\delta)(2-\frac{x}{s})}$ and the profits of the firm using the installed base policy in equilibrium are given by:

$\Pi_{IB}^* = (D-\frac{r^*}{s})\{Er^*+K\}.$

Similarly, $\Pi_{SE}$ is quadratic in $p$, and of the form

$\Pi_{SE} = \frac{1}{s}(r-\frac{p}{1+\delta})\{FP+G\}$ where $F = \frac{1}{2}-x+\frac{x}{2s}$, $G = r\frac{(1+\delta)}{2}(1-\frac{x}{s})-c.$

The equilibrium reaction function $p$ from the FOC is then given by:

$p^* = \frac{(1+\delta)Fr-G}{2F}$

$\Rightarrow p^* = \frac{(1+\delta)rx+cs-(1+\delta)rxs}{s+x-2sx}$ and the profits of the firm using the selling policy in equilibrium are given by:

$\Pi_{SE}^* = \frac{1}{s}\frac{[Fr(1+\delta)+G]^2}{4F(1+\delta)}.$

Simplifying $\Pi_{SE}^*$ by substituting the reaction function $p^*$ gives us:

$\Pi_{SE}^* = \frac{[(1+\delta)r(1-x)-c]^2}{(1+\delta)(s+x-2sx)}.$

Case 1: If $0 < x \le \frac{1}{2}$, then $\Pi_{SE}^*$ is maximized by minimizing the value of $(s+x-2sx)$ since $\Pi_{SE}^* = \frac{[(1+\delta)r(1-x)-c]^2}{(1+\delta)(s+x-2sx)}$, and $s^* = 1$.

Substituting $s^* = 1$ in the equilibrium reaction functions $r^*$ and $p^*$ and simplifying the resulting profit functions gives us the result in the proposition.

Case 2: If $\frac{1}{2} < x \le 1-c$, then the value of $\Pi_{SE}^*$ is maximized by minimizing the value of $(s+x-2sx)$ since $\Pi_{SE}^* = \frac{[(1+\delta)r(1-x)-c]^2}{(1+\delta)(s+x-2sx)}$.

$(s+x-2sx) = s(1-2x)+x \Longrightarrow (s+x-2sx)$ is minimized when $s = 0 \Longrightarrow s^* = 0$.

Substituting $s^* = 0$ the equilibrium reaction function $p^*$ gives: $p^* = (1+\delta)r$.

Hence, for the seller, the equilibrium reaction functions are given by: $p^* = (1+\delta)r$ and $s^* = 0$

$\Longrightarrow$ Both firms offer the same one-part tariff structure, hence, consumers choose the tariff structure that is cheaper, and only one mechanism can exist in the market.

The consumer utility surplus for the installed base and selling policies are given by:

$U_{IB}(v) = (1+\delta)(v-r)$, $U_{SE}(v) = (1+\delta)v - p.$

**Table 2**
Payoff matrix if one firm uses selling, competitor uses IBM.

| Profits for firms in mixed equilibrium strategy | | |
|---|---|---|
| | sell | IBM |
| sell | (0,0) | $(\Pi_s, \Pi_{IB})$ |
| IBM | $(\Pi_{IB}, \Pi_S)$ | (0,0) |

If $(1+\delta)r > p$, then the firm using the installed base policy is priced out, while if $(1+\delta)r < p$, the selling policy is priced out.

If the installed base policy offers a higher utility than selling, $\Pi_{IB} = (1-\nu_r)\{(1+\delta)r - c + \delta V - \frac{x}{2}(1+\delta)(1+\nu_r)\}$.

Since $U_{IB}(\nu) = (1+\delta)(\nu - r)$, if the installed base policy is the only mechanism in the market, the lowest value of $r$ is given by:

$\Pi_{IB} > 0 \Longrightarrow (1+\delta)r - c + \delta V - \frac{x}{2}(1+\delta)(1+r) > 0$

$\Longrightarrow r^*_{\min} = \frac{2c-2\delta V + x(1+\delta)}{(1+\delta)(2-x)}$, since $\nu_r = r$.

Similarly, if the selling policy is the only mechanism in the market, since $U_{SE}(\nu) = (1+\delta)\nu - p$,

$\Pi_{SE} = (1 - \frac{p}{1+\delta})[p - c - (1+\delta)\frac{x}{2}(1+\frac{p}{1+\delta})]$ since $s^* = 0$

$\Rightarrow p^*_{min} = \frac{2c+x(1+\delta)}{2-x} \Longrightarrow (1+\delta)r^*_{\min} = \frac{2c-2\delta V+x(1+\delta)}{(2-x)} < p^*_{min}$

$\Rightarrow p^* = p^*_{min} = \frac{2c+x(1+\delta)}{2-x}$

$(1+\delta)r^* = p^*_{min} - \epsilon,\ \epsilon \longrightarrow 0.$

Substituting the values of $r^*$, $p^*$ and $s^* = 0$ in the profit functions gives us the result in the proposition.

To show that $r^*$, $p^*$ and $s^*$ constitute an equilibrium, note that if the selling firm uses a servicing charge, we have shown that the equilibrium reaction function $s^*$ of the selling firm is given by $s^* = 0$.

(i) $p < p^* = p^*_{min}$ : For the selling firm, $p^* = p^*_{min} = \frac{2c+x(1+\delta)}{2-x}$. If $p^* < p^*_{min}$, $\Pi_{SE} < 0$ since $\Pi_{SE} = (1-\frac{p}{1+\delta})[p - c - (1+\delta)\frac{x}{2}(1+\frac{p}{1+\delta})]$ and $p - c - (1+\delta)\frac{x}{2}(1+\frac{p}{1+\delta}) < 0$ if $p^* < p^*_{min}$.

(ii) $p > p^* = p^*_{min}$ : If $p^* > p^*_{min}$, the market share of the selling firm is still zero as $\frac{p}{1+\delta} > r^* = \frac{2c+x(1+\delta)}{2-x} - \epsilon$.

(iii) $r > r^*$ : For the firm using the installed base policy, if $r > r^* = \frac{2c+x(1+\delta)}{2-x} - \epsilon$, then $\Pi_{IB} = 0$, as $r > \frac{p^*}{1+\delta}$.

(iv) $r < r^*$: Note that in the monopoly, the optimal rent is given by $\frac{(1+\delta)+c-\delta V}{(1+\delta)(2-x)}$ from Proposition 1.

In the duopoly, $r^* = \frac{2c+x(1+\delta)}{2-x} - \epsilon < \frac{(1+\delta)+c-\delta V}{(1+\delta)(2-x)}$ as $x + c < 1$ by assumption.

Hence, $r < r^*$ results in lower profits for the firm in equilibrium. □

**Proof of Proposition 5.** To find the mixed-strategy equilibrium profile of the normal game in Tabel 2, let the profit of the seller from this asymmetric Nash equilibrium be $\Pi_{SE}$ and the profit of the firm using the installed base mechanism be $\Pi_{IB}$. Then, we have the following payoff matrix for the two firms:

From Dixit and Shapiro (1986), each firm can also adopt a mixed strategy in a Nash equilibrium, in which the probability $\sigma_{SE}$ of selling makes the other firm indifferent between the selling and installed base mechanisms:

$$\sigma_{SE}(0) + (1-\sigma_{SE})\Pi_{SE} = \sigma_{SE}\Pi_{IB} + (1-\sigma_{SE})(0)$$

$$\sigma_{SE} = \frac{\Pi_{SE}}{\Pi_{SE} + \Pi_{IB}}$$

Therefore, in the unique mixed-strategy equilibrium, each firm chooses the selling mechanism with a probability of $\sigma_{SE} = \frac{\Pi_{SE}}{\Pi_{SE}+\Pi_{IB}}$ and the installed base mechanism with a probability of $1 - \sigma_{SE} = \frac{\Pi_{IB}}{\Pi_{SE}+\Pi_{IB}}$. □

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