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Is Servicization a Win-Win Strategy? Profitability and Environmental Implications of Servicization

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Problem definition: Servicization is a business strategy to sell the functionality of a product rather than the product itself. It has been touted as an environmentally friendly strategy as it encourages manufacturers to take more responsibility for their products. We study when servicization results in a *win-win* outcome where it can simultaneously increase a firm's profits and decrease its environmental impact compared to selling products.

Academic/Practical Relevance: While policy planners are interested in strategies that reduce environmental impact, firms are unlikely to embrace them if they are not profitable. Hence, understanding when servicization results in a win-win outcome is critical both for firms and policy-makers.

Methodology: We construct a stylized game theoretic model that takes into account several key dynamics not accounted in prior literature. In particular, we allow the servicizing firm to tailor the service to consumers' needs, endogenize product durability choice, and also use an environmental impact metric that captures the low discretionary use nature of products.

Results: For products that have low use impact relative to their production and disposal impacts, servicization can be a win-win strategy only if the firm has a sufficiently high operating efficiency. In contrast, for products that have high use impact relative to their production and disposal impacts, servicization can be a win-win strategy only if the firm has a sufficiently low operating efficiency and the consumer segments are adequately similar. Furthermore, servicization can improve consumer welfare and simultaneously improve profitability and environmental impact only for low relative use impact products.

Managerial Implications: Whether servicization leads to a win-win outcome cannot be simply determined by changes in product durability as often argued. It critically depends on the firm's relative operating efficiency, environmental impact of product in its use phase relative to the production and disposal phases, and the similarity of consumer segments. Our results explicitly characterize these relations.

Key words: servicization; environmental impact; profitability; product durability

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1. Introduction

There has been a structural economic shift to services from manufacturing in the US and other advanced industrial countries over the last century. While the contribution of manufacturing to the

US economy has shrunk, the contribution of the service sector has increased by over 200% in the post-1950 era (White et al. 1999). A recent report of the US Department of Commerce (April 2013) shows that the service sector comprises 80.3% of the US GDP (US Department of Commerce 2013). Services also now constitute more than 80% of the US employment (Bureau of Labor Statistics 2013).

There have been significant innovations in the service economy with radical changes and additions to its structure. Traditional services, which generally rest upon the provision of labor and expertise, not physical goods, are not the only kinds of services anymore. Manufacturers have started using their products as means for service delivery; not the end.

These business models are called product-service systems. Some of these product-service systems are of the more familiar kind where the manufacturers sell services *along* with the products, such as warranties and maintenance services for autos and other durable goods. In others, manufacturers sell services *instead* of products. The latter type of product-service system is referred to as servicization. While various notions of servicization have been conceptualized (Toffel 2002), we adopt the commonly used definition of servicization where the manufacturer sells the functionality of the product rather than the product itself, i.e., the manufacturer owns and incurs the cost to operate the product while the customer pays for the use and the value derived from the use of the product.

According to this definition, there are two distinctive features of servicization as compared to selling or leasing products: payments based on the amount of use of a product and the inclusion of the operating cost including maintenance and supplies in the service agreement. For example, Rolls Royce offers its customers power-by-hour contracts where Rolls Royce retains the ownership of the engines, maintains them regularly, and the customers only pay based on number of hours they use the engines (Swartz 2014). AB Electrolux installs washing machines in a customer's home, maintains and repairs them regularly, and charges customers by the laundry load (Electrolux 1999). Other examples of servicization include Interface Inc. (Modular Carpet), Caterpillar (Earth Moving), Bombardier (Transportation Services), Better Place (Electric Cars) (Rothenberg 2007). Hawken (2010) nicely summarizes the idea behind servicization: "What we want from these products is not ownership per se, but the service that the products provide; transportation from our car, cold beer from the refrigerator, news or entertainment from our television."

The arguments supporting servicization draw on two themes: profitability and environmental benefits. From a profitability perspective, servicization offers firms unique opportunities by allowing service differentiation (Bustinza et al. 2015, White et al. 1999). This can be done through identifying the use needs of the different consumer segments and offering contracts with different use durations. In some sense, servicization allows the firm to control the level of product use by consumers. This lever allows the firm to segment the market more efficiently and potentially increase its profitability.

Hence, customer segmentation is an important attribute of servicization that we capture in our model by allowing the firm to offer different use-based contracts.

From the environmental perspective, servicization encourages manufacturers to take more responsibility for their products because the operating cost is incurred by manufacturers under servicization. This may decrease the environmental impact of a product by incentivizing manufacturers to design more durable products that would decrease the material use intensity (Toffel 2002). Thus, adoption of servicization can lead a firm to change its product attributes, and, in particular, the durability of its products. Arguably, this may lead to a lower environmental impact.

Despite these compelling arguments regarding the profitability and environmental benefits, many manufacturers are reluctant to adopt servicization, and some have failed to implement it profitably. Ray Anderson, an entrepreneur with an environmental focus, embraced the servicization idea at Interface Inc. However, Interface faced significant obstacles in implementing the servicization idea. The challenges of selling this idea to a customer (University of Texas) have been documented in a well-known case (Oliva and Quinn 2003). From a practical perspective, a firm is unlikely to embrace servicization if it is not a profitable strategy, even when it has environmental benefits. In addition, it has also been argued that servicization does not necessarily incentivize the profit maximizing manufacturers to design products with lower environmental impact (White et al. 1999). Thus it is important to understand when servicization *simultaneously* leads to an increase in profits and reduce environmental impact. The primary goal of this paper is to analytically investigate the arguments *for/against* servicization and characterize when servicization creates a win-win outcome by increasing the firm's profit and decreasing the environmental impact. In what follows, we outline some of the key features of servicization that we capture in our analysis.

First, product durability has long been seen as a sustainable product feature because it potentially extends the length of the use phase of a product (E.C. 2014). For example, current European Commission policy strategies promote product durability: "Moving away from a wasteful economy towards one based on durability and repairability of products is likely to create job opportunities throughout the product life-cycle in terms of, maintenance, repair, upgrade, and reuse" (E.C. 2012). However, this view of product durability discounts the environmental impact of a product during its use phase. If a products stays in use for a longer time with decreasing use efficiency, its environmental impact may increase because of this drop in use efficiency. On the other hand, if a product stays in use for a longer time, it can spread its environmental impact incurred during the production and disposal of the product over a longer horizon which may decrease its overall environmental impact. Therefore, the environmental impact depends on the trade-off between the environmental impact incurred during the product use, production, and disposal phases. Hence, we capture the environmental impact of a product in our model through these three life stages of the product by endogenizing the product durability choice.

To develop our environmental impact metric, we focus on products with low discretionary use since several products under consideration for servicization are of this type. We assume that product features, such as product durability, do not change the consumer use *intensity* but may change how long the consumer keeps the product. For instance, more durable carpets are likely to be used for a *longer time period*.

Second, operating cost of a product impacts the profitability of servicization. Consumers' operating cost might be higher or lower than the firm's operating cost because consumers and the firm may have different levels of effectiveness in operating the product. For example, in its proposed contract with the University of Texas, Interface carpet stated a higher maintenance cost per square feet than UT's own established janitorial service (Oliva and Quinn 2003). On the other hand, the firm may benefit from economies of scale, and may have a lower operating cost. However, a lack of sense of ownership may lead to abuse of equipment, and eventually increase the maintenance cost of the product under servicization. If the firm has a very high relative operating cost compared to the customer, then servicization may not be as profitable as the traditional selling strategy. Thus, the relative difference in a firm's and consumer's operating cost (relative operating efficiency) is an important factor that can affect the profitability of servicization, which we capture in our model.

Additionally, operating cost of a product also impacts consumers' use durations. As a result, it impacts the environmental impact of a product under both selling and servicization strategies. For example, all else being equal, a higher operating cost incentivizes consumers to decrease their use durations under selling strategy. Similarly, a higher operating cost incentivizes firms to offer lower use durations to their consumers. However, even when the firm incurs a higher operating cost compared to consumers, servicization may not necessarily lead to lower use durations compared to selling strategy because of changes in market coverage. As a result, the impact of operating cost on the consumer use durations; and hence, the environmental impact is not clear cut and require further research.

On the demand side, we allow heterogeneity by assuming that the consumers belong to one of two segments with different product use valuations. This heterogeneity allows us to evaluate the impact of market segmentation on the profitability of servicization. In addition, consumers' product use duration is endogenously determined in the equilibrium and depends on the product characteristics and the consumer types. On the supply side, we endogenize both the price and the product durability decisions. Under selling, the manufacturer decides on the sales price of its product whereas it can offer different use based contracts tailored for two segments under servicization. Therefore, the manufacturer has more levers to control consumer purchase and use behavior under servicization. In contrast to selling, the firm incurs the operating cost under servicization.

A summary of our analysis and key findings are as follows: First, we analytically characterize the equilibrium product durability, pricing and consumer use decisions under both selling and servicization strategies. We then analytically compare the profits. We show that servicization strategy can be more profitable even when the firm is operationally less efficient than consumers. This is because the servicizing firm can utilize product use information to offer customized prices to each consumer segment. A commonly held belief is that servicization increases product durability because it increases the firm's responsibility toward its product. We show that this intuition is correct when the firm serves the same consumer segments under selling and servicization strategies. However, when the firm targets more consumer segments under servicization, servicization may actually lower product durability.

We find that whether servicization is greener and more profitable depends on the firm's relative operating efficiency, the relative environmental impact of product in its use phase as compared to the production and disposal phases, and the valuation gap between the consumer segments. For products that have low use impact relative to their production and disposal impacts, servicization can be more environmentally friendly and profitable if the firm has higher operating efficiency relative to consumers. In contrast, for products that have high use impact relative to their production and disposal impacts, servicization can be more environmentally friendly and profitable only if the firm has a lower relative operating efficiency *and* the valuation gap between the consumer segments is sufficiently low. We also study the impact of servicization on consumer welfare. We find that servicization can improve consumer welfare and simultaneously improve profitability and environmental impact only for low relative use impact products. Thus, while servicization as a business strategy holds promise, it should be implemented with care.

2. Literature Review

A stream of research in the sustainable operations literature studies the impact of various business strategies and regulations on the profitability of firms and the environment: some of these are related to extended producer responsibility (Plambeck and Wang 2009, Atasu and Subramanian 2012), competition in product recovery (Örsdemir et al. 2014, Ferrer and Swaminathan 2006), carbon emissions (Drake et al. 2012), leasing of electric car batteries (Lim et al. 2014) and durable goods (Agrawal et al. 2012). We contribute to this literature by analyzing the profitability and environmental implications of servicization.

An emerging stream of papers has studied different aspects of servicization. Avci et al. (2014) study the adoption of electric vehicles when the consumers are charged based on how much they drive rather than paying for the battery upfront. Agrawal and Bellos (2016) study the environmental impact of servicization with and without resource pooling. Our paper differs from Agrawal and Bellos (2016), Avci et al. (2014) as well as Agrawal et al. (2012) in several aspects. These papers assume that consumers and the firm effectively incur identical operating costs to keep the product operational, that is, they do not allow for operating cost asymmetry. This cost asymmetry plays a critical role in determining when servicization results in a win-win for the firm and the environment in our model. In addition, these papers do not allow the firm to offer a menu of choices (e.g., use durations) to customize its offering for each consumer segment. White et al. (1999) point that this ability to segment the market can be a critical advantage of servicization business model and our model captures this benefit. While Agrawal and Bellos (2016) find that pure servicization can never be more profitable than selling without pooling benefits, we show that it can be more profitable even without pooling benefits because of this segmentation benefit. Furthermore, we show that product durability can decrease under servicization compared to selling strategy because of this segmentation. In contrast, Agrawal et al. (2012) shows product durability never decreases under leasing and Agrawal and Bellos (2016), Avci et al. (2014) do not consider product durability at all.

Additionally, the environmental impact metric in Agrawal and Bellos (2016), Avci et al. (2014) assumes consumers' use intensity over a *fixed* period of time depends on their operating cost or pay-per-use price. This assumptions is appropriate for high discretionary use products. We, on the other hand, consider low discretionary use products, and assume constant use intensity but allow use duration to be chosen endogenously. This endogenous use duration results in a trade-off between the relative importance of environmental impacts during use phase and production and disposal phases. Our environmental impact metric captures this trade-off and we provide a careful characterization in our paper.

Conceptual and case studies on servicization (Toffel 2002, White et al. 1999, Stoughton et al. 2009) have been very useful in defining the value of servicization for both the firms and environment by providing anecdotal evidence. In our work, we use an analytical framework to scientifically address the research questions, instead of relying on anecdotal evidence.

In the durable goods literature, several papers study the profitability of leasing versus selling from different perspectives, such as the effect of product depreciation rate (Desai and Purohit 1998), competition (Desai and Purohit 1999), channel structure (Bhaskaran and Gilbert 2009), and presence of a complementary product (Bhaskaran and Gilbert 2005). However, these works are concerned with neither the environmental impact of different strategies nor with the operating cost of products.

In the contracting literature, a number of papers study the impact of performance based contracts (PBC) on supply chain alignment (Li and Mishra 2017, Kim et al. 2007, 2010, Guajardo et al. 2012). Although, PBC can be considered as a variant of servicization, this literature does not analyze the environmental impact of PBC. We contribute to this literature by explicitly considering the environmental impact of servicization. Yadav et al. (2003) and Corbett and DeCroix (2001) study shared saving contracts in supply chains for indirect materials. In contrast, we focus on the impact of servicization on the final product itself. In particular, we study the impact of servicization on the product design by endogenizing the product durability.

3. Model Overview

We consider a monopolist who produces a single product and either sells or servicizes its product to consumers. In the following, we first introduce the consumer and product characteristics, and then discuss the consumers' and firm's decisions.

3.1. Consumer and Product Characteristics

The firm sells or servicizes its product in a market characterized by two consumer segments. Consumers in these two market segments differ in their valuation of the product. The two consumer segments are characterized by θ_i, $i = H, L$, where θ_H and θ_L show the valuations of high and low end segments, respectively. We assume $\theta_H = \theta$ and $\theta_L = \alpha\theta$ where $\alpha \in (0,1)$. The mass of potential consumers is M and $\beta \in (0,1)$ shows the fraction of θ_H consumers. Multiple consumer segments may arise due to differing needs and/or internal constraints of consumers. For example, Oliva and Quinn (2003) document that while Interface was offering 5-year and 7-year length service agreements to their commercial customer, University of Texas at Houston, a nonprofit organization, asked Interface for a 10-year service agreement. Firms, recognizing the existence of different consumer segments, conduct customized outreach to their customers and also structure their organizations to satisfy the needs of different consumer segments. For example, Interface acknowledges the different consumer segments by classifying them as corporate, higher education, K-12 etc. (Interface 2016). Similarly, Fuji Xerox acknowledges that their consumer base consists of different customer segments: some consumers are heavy users of copiers while others are light users of copiers (FujiXerox 2016).

θ_i represents consumer segment i's utility from the first use of a product. The utility derived from the product deteriorates with each additional use. The deterioration rate depends on the product durability, δ, that is, it will be slower for products with higher durability. Specifically, the consumer *marginal utility per unit use* is $\theta_i - \frac{t}{\delta}$, $i = H, L$. Here, the marginal utility decreases by $\frac{t}{\delta}$ after each t units of use. This utility specification is similar to those of Agrawal and Bellos (2016), Lambrecht et al. (2007) and Gilbert and Jonnalagedda (2011) in the sense that they too assume marginal utility decreases after each unit of use. Furthermore, the assumption that more durable products deteriorate more slowly is common in the durable goods literature (Desai and Purohit 1998, 1999).

There is a cost of operating the product. This cost includes maintenance and all other costs incurred to keep the product operational. When the consumers own the product (which is the case under selling), the consumers incur the operating cost; otherwise, when the firm owns the product (which is the case under servicization), the firm incurs the operating cost. For example, for copiers the operating cost includes maintenance, toners, papers etc. For instance, University of California Davis and Oregon State University have adopted servicization contracts for their copier needs (U.C.D 2014, O.S.U 2014) where the manufacturer incurs all operating costs. The consumers and the firm may differ in their operational efficiency to operate the product, i.e., for the same amount of use the firm can incur higher or lower total operating cost than the consumers. For example, in its failed deal attempt with University of Texas at Houston, Interface carpet stated a higher maintenance cost per square feet than UT's own established janitorial service, (Oliva and Quinn 2003). Furthermore, as Bardhi and Eckhardt (2012) point out, when a consumer does not own the product, her use behavior toward the product changes. When a consumer owns the product, she has incentive to use the product properly because misuse of the product will increase her product maintenance cost. This incentive disappears in the servicization model as the firm bears the operating cost, as a result the firm may incur a higher operating cost for the same use duration. On the other hand, economies of scale may lower operating cost for the firm. Hence, our model allows for the operating cost to be higher or lower for the firm than the consumer.

Since more durable products require less maintenance and are expected to lose their energy efficiency at a slower rate, we assume that the operating cost is decreasing in product durability δ. In addition, we assume that total operating cost is increasing convex in use τ. This is because, as the product is used more, it may require more frequent repairs and may be less energy efficient (Deshpande et al. 2006, Desai and Purohit 1998, Iravani and Duenyas 2002). Xerox acknowledges this fact when making stocking decisions of the spare parts for its copiers (Bacon 2013). Thus, we assume that marginal operating cost increases linearly with the product use. In order to capture all these features, we use the following operating cost functions: when the consumer or the firm owns the product, they incur an operating cost $\frac{m_i \tau^2}{2\delta}$, $i = c, f$, where m_c and m_f denote the operating cost parameters for the consumer and the firm, respectively. m_c can be lower or higher than m_f as explained earlier.

3.2. Consumer and Firm Decisions

In this section, we first introduce the consumers' and firm's problems for the selling strategy, and then for the servicization strategy. We consider a static model that allows a single purchase by a consumer. In particular, our model assumes that the firm maximizes its profit for a *single* generation of a product. This assumption is made because it is unreasonable to assume that a firm can lock consumers into making repeated purchases of future generations of the product. Indeed, consumers are becoming increasingly less loyal (Llopis 2014, Leinbach-Reyhle 2016) as a result of abundance of choices coupled with increasing price transparency and lower search costs. Furthermore, it is well documented that the firms and managers tend to focus on short term gains and behave myopically due to earnings pressures and shrinking management tenures among other things (Mizik and Jacobson 2007, Stein 1989, Cheng 2004, Olesinski et al. 2014).

In the case of selling, on the demand side, each consumer first decides whether to purchase the product. If type θ_i consumer buys the product, she then determines her level of use τ, to maximize her utility:

$$U_c(\theta_i) = \max_{\tau} \int_0^{\tau} (\theta_i - \frac{t}{\delta})dt - \frac{m_c\tau^2}{2\delta} - p. \quad (1)$$

Marginal utility per unit use is integrated over the use duration to obtain consumer's utility in Eq. (1), then the total operating cost and the product price p are deducted. The consumer stops using the product and the product is disposed, once its marginal utility per unit use drops below the marginal operating cost per unit use. We assume that there is no disposal cost or salvage value.

On the supply side, the firm determines the product durability δ. We assume that the production cost is convex in product durability and is equal to $k\delta^2$, where k is a positive scaling parameter. The firm then sets the sales price p. Because the high valuation segment has a higher willingness-to-pay, serving only the low valuation segment is never feasible. Let $\pi^*_{c,B}$ and $\pi^*_{c,H}$ denote the manufacturer's optimum profit when it sells to both segments and only to θ_H segment, respectively. If $\pi^*_{c,B} \geq \pi^*_{c,H}$, the manufacturer sells to both segments; otherwise it sells only to high valuation segment. $\pi^*_{c,B}$ and $\pi^*_{c,H}$ are given by:

$$\begin{aligned} \pi^*_{c,B} &= \max\nolimits_{p,\delta}(p - k\delta^2)M, && (2)\\ s.t. &\quad U_c(\theta_L) \geq 0. \\ \pi^*_{c,H} &= \max\nolimits_{p,\delta}(p - k\delta^2)M\beta, && (3)\\ s.t. &\quad U_c(\theta_H) \geq 0. \end{aligned}$$

As customary, we normalize the utility of outside option to zero (cf. Laffont and Martimort 2009 p.34). If the firm sells to both segments, low valuation segment θ_L must receive at least the value of the outside option, i.e., $U_c(\theta_L) \geq 0$. Similarly, if the firm sells only to the high valuation segment θ_H, high valuation segment must capture at least the value of the outside option, $U_c(\theta_H) \geq 0$.

In the case of servicization, on the demand side, consumers choose one of the contract options offered by the firm, including not receiving any service. As in the selling strategy, we normalize the value of the outside option to zero. Each contract option specifies a use-price pair, i.e., (τ_i, F_i), $i = H, L$. Consumers choosing the contract (τ_i, F_i) use the product for τ_i units and pays the firm F_i. F_i includes all payments associated with use and servicing of the product.

On the supply side, the firm determines the product durability δ and the parameters of the menu contract (τ_i, F_i), $i = H, L$. Similar to the selling strategy, because the high valuation segment has a higher willingness-to-pay, inducing only the low valuation segment to purchase the service is never feasible. If the firm induces both segments to purchase the service, the menu must satisfy the following individual rationality and incentive compatibility constraints.

$$IR_i : \int_0^{\tau_i} (\theta_i - \frac{t}{\delta})dt - F_i \geq 0, \qquad i = H, L \tag{4}$$

$$IC_i : \int_0^{\tau_i} (\theta_i - \frac{t}{\delta})dt - F_i \geq \int_0^{\tau_j} (\theta_i - \frac{t}{\delta})dt - F_j, \qquad i \neq j, \text{and } i, j = H, L. \tag{5}$$

Otherwise, if the firm induces only high valuation segment to accept the offer, then the contract only needs to satisfy individual rationality constraint of the high valuation segment, i.e., IR_H. Let $\pi^*_{f,B}$ and $\pi^*_{f,H}$ denote the manufacturer's optimum profit when it serves both segments and only the θ_H segment, respectively. Then,

$$\pi^*_{f,B} = \max_{\delta, F_i, \tau_i, i=H,L} \sum_{i=H,L} (F_i - \frac{m_f \tau_i^2}{2\delta} - k\delta^2)Q_i, \tag{6}$$

$$s.t. \; IR_i, \; IC_i \quad i = H, L.$$

$$\pi^*_{f,H} = \max_{\delta, F_H, \tau_H} (F_H - \frac{m_f \tau_H^2}{2\delta} - k\delta^2)Q_H, \tag{7}$$

$$s.t. \; IR_H.$$

where Q_L and Q_H show the segment sizes, i.e., $Q_L = (1-\beta)M$ and $Q_H = \beta M$. The firm serves both segments if $\pi^*_{f,B} \geq \pi^*_{f,H}$; otherwise, it serves only θ_H segment.

4. Analysis

In this section, we first characterize the equilibrium choices of consumers and the firm under selling and servicization. Then, we compare these equilibrium outcomes to understand the impact of servicization on profitability and product durability.

4.1. Equilibrium

The next proposition describes the equilibrium decisions for both selling and servicization strategies. As will be evident, the ratio $\frac{\alpha}{\beta}$ plays a critical role in the characterization of equilibria. This ratio shows the relative profitability of serving the low-end segment. Increasing $\frac{\alpha}{\beta}$ indicates either the valuation or the mass of the low end segment increases. Therefore, when this ratio increases, the profitability of serving the low valuation segment increases, and vice versa.

Proposition 1. *The following characterizes the equilibrium regions. The optimum product durability, product use and firm profits are provided in Table 1.*

$(R1)$ *When* $\frac{1}{\beta^{3/4}} \leq \frac{\alpha}{\beta}$, *the firm serves both segments under both selling and servicization strategies.*

$(R2)$ *When* $\gamma(\alpha,\beta) \leq \frac{\alpha}{\beta} < \frac{1}{\beta^{3/4}}$, *the firm serves high valuation segment under the selling strategy and both segments under the servicization strategy.*

$(R3)$ *When* $0 < \frac{\alpha}{\beta} < \gamma(\alpha,\beta)$, *the firm serves only the high valuation segment under both selling and servicization strategies.* $\gamma(\alpha,\beta)$ *is characterized in the proof of the proposition.*

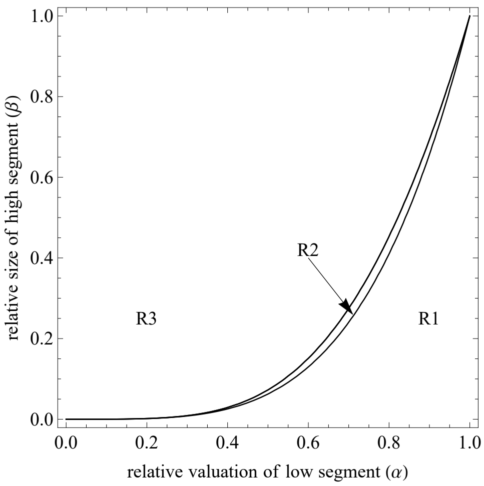


Figure 1 **Illustration of equilibrium regions under selling and servicization strategies.**

Strategy	Regions	δ^*	τ^*	π^*
Selling	$R1$	$\frac{\alpha^2\theta^2}{4k(1+m_c)}$	$\tau_H^* = \frac{\theta\delta^*}{1+m_c},\ \tau_L^* = \frac{\alpha\theta\delta^*}{1+m_c}$	$\frac{a^4\theta^4 M}{16k(1+m_c)^2}$
	$R2,\ R3$	$\frac{\theta^2}{4k(1+m_c)}$	$\tau_H^* = \frac{\theta\delta^*}{1+m_c},\ \tau_L^* = 0$	$\frac{\theta^4\beta M}{16c(1+m_c)^2}$
Servicization	$R1,\ R2$	$\frac{\left(\alpha^2+\beta-2\alpha\beta\right)\theta^2}{4k(1-\beta)(1+m_f)}$	$\tau_H^* = \frac{\theta\delta^*}{1+m_f},\ \tau_L^* = \frac{(\alpha-\beta)\theta\delta^*}{(1-\beta)(1+m_f)}$	$\frac{\left(\alpha^2+\beta-2\alpha\beta\right)^2\theta^4 M}{16k(1-\beta)^2\left(1+m_f\right)^2}$
	$R3$	$\frac{\theta^2}{4k(1+m_f)}$	$\tau_H^* = \frac{\theta\delta^*}{1+m_f},\ \tau_L^* = 0$	$\frac{\theta^4\beta M}{16k(1+m_f)^2}$

Table 1 **Equilibrium product durability, use duration and profit under selling and servicization strategy.**

Figure 1 graphically depicts the equilibrium regions in Proposition 1. Note that the equilibrium regions depend on only $\frac{\alpha}{\beta}$ ratio. As we move from $R1$ to $R3$, $\frac{\alpha}{\beta}$ ratio decreases, and serving the low end segment becomes relatively less profitable. In fact, the firm abandons low end consumer segment when $\frac{\alpha}{\beta}$ ratio is smaller than a certain threshold. This happens because when the firm serves both segments, the low end segment only receives its reservation utility, but the high end segment receives an additional informational rent, which increases as $\frac{\alpha}{\beta}$ ratio decreases. In this case, either β increases, and hence the relative market size of consumers receiving informational rent increases, or α decreases, and hence the firm needs to decrease its price to appeal to the low-end segment. When the informational rent becomes too high, it is more profitable for the firm to serve only the high-end consumers.

Note that the firm is more likely to abandon the low-end segment under the selling strategy compared to servicization. When $\frac{\alpha}{\beta}$ ratio is moderate as in $R2$, the firm serves both segments when it servicizes the product, but serves only the high-end segment when it sells the product. Thus, servicization can lead to *market expansion.* This result follows from the fact that the servicization strategy enables the firm to control consumers' use durations. Thus, the servicizing firm can induce the consumer segments to use the product at a more efficient level from a profitability perspective, and extract a higher portion of the consumer surplus. Therefore, the firm can continue to serve

Variable	α	β
f_1	$\uparrow$	$\downarrow$
f_2	$\downarrow$	$\uparrow$

Table 2 Comparative statics in Proposition 2 for f_1 and f_2. f_1 and f_2 are explicitly stated in the proposition

the low-end consumer segment. Note that the result is independent of the consumer and the firm's operating costs and continues to hold even when firm has a high operating cost.

Table 1 shows that, regardless of the targeted segments, product durability decreases when the operating cost increases: consumers' and firm's operating costs respectively in selling and servicization strategies. Essentially, the benefit of extending the product's useful lifetime by improving its durability is lower when the operating cost is higher.

Table 1 shows that when the firm sells its product, the optimal durability choice does not depend on relative size of the segments, which is determined by β. In contrast, when the firm servicizes the product, the optimal durability may depend on the size of each segment. Essentially, when the firm sells the product, it cannot differentiate among customers based on their use durations. In this case, optimal product configuration is determined by the lowest segment that the product needs to attract. In contrast, the firm can offer differentiated offerings based on use durations in the case of servicization. When β increases, high segment becomes relatively more important, and the firm wants to create a bigger separation between the two segments by increasing the use duration of the high segment and decreasing it for the low segment. Thus, the firm improves product durability to extend the use duration of the high segment.

4.2. Profitability

In this section, we study how servicization affects the profitability of a firm. As will be evident, $r \triangleq \frac{1+m_c}{1+m_f}$ ratio, simply referred to as the *relative operating efficiency of the firm* plays an important role in our results. When r decreases, relative cost advantage of servicization decreases and vice versa for selling. This is because decreasing r indicates either the firm's operating cost goes up or the consumers' operating cost goes down. The next proposition compares profitability of selling and servicization strategies.

PROPOSITION 2. *(Profitability) Servicization is more profitable than the selling strategy if and only if*

(i) $r > \frac{\alpha^2(1-\beta)}{\alpha^2+\beta-2\alpha\beta} \triangleq f_1$ *in* $R1$.

(ii) $r > \frac{(1-\beta)\sqrt{\beta}}{\alpha^2+\beta-2\alpha\beta} \triangleq f_2$ *in* $R2$.

(iii) $r > 1$ *in* $R3$.

Furthermore, $f_1, f_2 < 1$. *Table 2 shows how* f_1 *and* f_2 *change with* α *and* β.

Recall that regions $R1$-$R3$ are characterized in Proposition 1, and they depend only on the $\frac{\alpha}{\beta}$ ratio. Because $f_1, f_2 < 1$, the proposition indicates that the firm may find it attractive to keep the ownership and servicize its product even when consumers are more efficient in operating the product, that is, when they have a lower operating cost. This happens when the low end segment is sufficiently profitable ($\frac{\alpha}{\beta}$ is sufficiently high) so that the firm chooses to serve both segments under servicization.

Servicization can be more profitable even when it is operationally inefficient, because it allows the firm to track and control consumer use durations and utilize this information in pricing to extract more surplus from consumers. Therefore, the ability to control use durations can give servicization a pricing advantage.

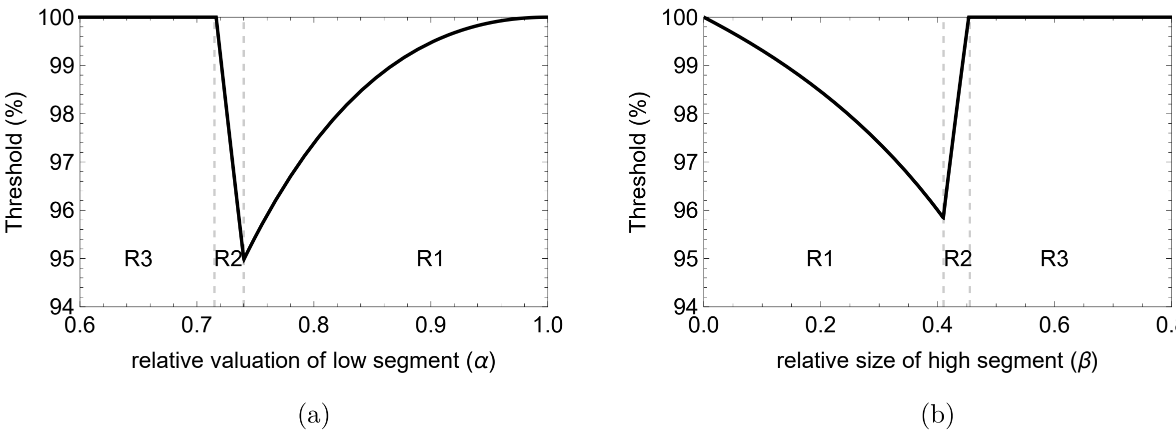


Figure 2 **The minimum operating efficiency above which servicization is more profitable than selling strategy. ($\beta = 0.3$ in (a) and $\alpha = 0.8$ in (b))**

Figure 2 shows the relative operating efficiency threshold above which servicization becomes more attractive.[1] The figure shows that servicization is more likely to be attractive when $\frac{\alpha}{\beta}$ ratio is moderate and the threshold has its minimum at $R1$-$R2$ boundary. Essentially, the pricing advantage of servicization as a result of controlling use durations becomes more valuable when the gap between valuations of low and high end segments (i.e., $1 - \alpha$) and relative mass of high end segment (i.e., β) increase. Therefore, in $R1$, where both segments are served under both strategies, decreasing $\frac{\alpha}{\beta}$ ratio makes servicization relatively more attractive. However, in $R2$, when low end segment is served under servicization strategy only, a smaller $\frac{\alpha}{\beta}$ makes low end segment to be relatively less profitable, which in turn makes selling more attractive. When $\frac{\alpha}{\beta}$ ratio is too small, only high end segment is served under both strategies. In this case, servicization does not have a pricing advantage, and relative

[1] Only α and β values are provided in the figure because thresholds are functions of only α and β. We use this convention throughout the paper unless other parameters may have an effect.

operating efficiencies determine the optimal choice: When the firm has a lower operating cost, $r > 1$, servicization is more profitable. This is also true for the extreme cases, i.e., when α or β is equal to 0 or 1, since in these cases there is only a single segment in the market. When $\alpha = 0.8$ or $\beta = 0.3$ (these are the parameters used in Figure 2), even when the firm and consumers have the same operating efficiencies, we found that servicization may increase the firm's profit by 10%.

Our results show that servicization can be preferable even when the firm is operationally less efficient than consumers. Indeed, the servicizing firm can have a higher operating cost than consumers, as seen in the Interface carpet example. Firms who are new to servicization may not be as operationally efficient as their consumers since building expertise and improving the processes of servicized offerings require time (Heal 2008). In addition, servicization weakens the consumers' incentives to use the product properly, which in turn may increase the operating cost of the firm under servicization.

Our results may also offer one possible explanation as to why Interface's servicization experiment did not succeed. In addition to its high operating cost, its contract design may have prevented servicization from being more profitable for Interface. Interface offered only one type of contract that fixed the product use length to 7 years in their Evergreen Lease program. This was required due to accounting restrictions on operating leases in some cases. However, even when UT Dallas, a tax exempt institution requested a 10-year contract, Interface declined this offer (Heal 2008). Electrolux, in its failed servicization attempt with its washing machines, followed a similar strategy and instead of segmenting the market, charged a single pay-per-use price from its customer (Russo 2008). Our results show that controlling use durations to segment the market can greatly increase profitability of servicization, and Interface and Electrolux could have benefited significantly by offering a menu of use durations and prices instead of a single fixed use duration and price.

4.3. Product Durability

It has been widely argued that, because the firm is responsible for the maintenance of the product, servicization would encourage firms to invest in product durability so that the product would need less frequent repairs (White et al. 1999, Stoughton et al. 2009, Toffel 2002). While these papers provide only qualitative arguments, here, we consider an analytical model. We find that servicization indeed increases product durability in many cases. However, we show this conjecture need not be always true: Servicization can decrease product durability in some cases.

This result is due to how servicization affects the firm's pricing policy which is captured in our model. The ability to control use durations through pricing enables the firm to target more consumer segments which may result in choosing a lower durability level. This result is formally stated in the following proposition. The proposition characterizes the result when servicization leads to higher profits than selling strategy because in a non-regulatory setting, the firm will adopt servicization only when profit is higher under servicization. Therefore, we study the impact of servicization on product durability when servicization is more profitable.

PROPOSITION 3. *(Durability) When servicization is more profitable than the selling strategy, servicization increases product durability over selling except when* $r < \frac{1-\beta}{\alpha^2+\beta-2\alpha\beta}$ *in* $R2$. *Furthermore,* $\frac{1-\beta}{\alpha^2+\beta-2\alpha\beta} > 1$.

The Proposition demonstrates that when servicization is attractive in regions $R1$ and $R3$, it always increases product durability. However, there are different dynamics in place in these regions. In $R3$, only the high segment is served under both strategies, and servicization is chosen only when $r > 1$, i.e., when consumers have a higher operating cost. Therefore, servicization results in a lower operating cost which makes it attractive to extend the useful lifetime of the product by increasing its durability. In contrast, in $R1$, servicization can be preferred even when the firm has a higher operating cost, i.e., $r < 1$. Here, both segments are served under both strategies. Because servicization enables segmentation based on use durations, the firm can extract a significantly higher surplus from the high end segment and, therefore, benefits more from extending the use duration by increasing product durability.

In $R2$, different from $R1$ and $R3$, the firm does not serve the same consumer segments under servicization, and it can result in a lower product durability. In particular, unlike the selling strategy, servicization now targets the low end segment, which may make it optimal to choose a less durable product. However, a sufficiently strong operating efficiency (i.e., $r > \frac{1-\beta}{\alpha^2+\beta-2\alpha\beta}$) may overcome this effect, and the servicization can still result in a more durable product despite targeting more consumer segments. Thus, there exist conditions under which servicization might *decrease durability* compared to the selling strategy.

Increased product durability, characterized in this section, has been considered as a key goal to decrease environmental burden of products (Toffel 2002). However, our results in §5.1 show that higher product durability as a result of servicization may not necessarily improve environmental impact. The relative significance of use, production and disposal related components of environmental impact, and relative operating efficiency of firm are critical in determining whether servicization leads to an improved environmental performance or not.

5. Environmental And Welfare Implications Of Servicization

In this section, we study the environmental and welfare implications of servicization.

5.1. Environmental Impact

Here, we first describe our environmental impact metric. We then study how servicization affects the environment using this metric. We follow the convention in the literature to quantify total environmental impact (Atasu and Souza 2013, Agrawal et al. 2012). One unit of product entails environmental impact over three life cycle phases: production, use and disposal. Environmental impact of one unit of product during the production and disposal phases are denoted by e_p and e_d, respectively. Environmental impact of one unit of product during the use phase is increasing convex in product use duration τ, and is given by $e_u\tau_i^2$. Convexity is assumed because the product's resource efficiency may decrease with use, which may increase per unit environmental impact during the use phase (Intlekofer 2009, White et al. 1999). Adding up these three components, the total environmental impact due to market segment i's consumption is given by $Q_i(e_p+e_d+e_u\tau_i^2)$.

We focus on the products with low discretionary use in our analysis. Furthermore, we assume that product features, e.g., product durability and price, do not change the consumer use intensity, i.e., product use per unit of time. For example, if a consumer uses a Xerox copier to copy a certain number of pages per month, that rate does not change regardless of price and durability of the product. In contrast, product lifecycle length is endogenously determined by the consumers' chosen use duration of the product. For example, when the consumers' chosen use duration is high, the consumer will keep the product for a longer time. Therefore, products may have different use durations. We need an environmental impact metric which can provide a fair comparison of products possibly with different use durations. Hence, we normalize the total environmental impact of one unit of product by dividing it by its use duration. Thus, the environmental impact per-unit-time, added over all market segments, is given by:

$$E_j = \sum_{i=H,L} \frac{(e_u\tau_i^2+e_p+e_d)Q_i}{\tau_i}, \quad j=c,f. \tag{8}$$

In contrast, the total environmental impact metric, i.e., $\sum_{i=H,L}(e_u\tau_i^2+e_p+e_d)Q_i$ has been used in Agrawal and Bellos (2016), Avci et al. (2014) to assess the environmental performance. These papers fix product use duration and, instead, consumers choose product use intensity based on product characteristics. This assumption is appropriate when a product has high discretionary use, such as leisure and entertainment goods, and, hence, consumers are likely to alter their consumption intensity based on price or other product characteristics. However, products such as Interface carpet, Xerox copiers and Electrolux washing machines, have low discretionary use and consumers' use intensity does not significantly depend on the product characteristics. Instead, product characteristic may alter the product use duration. For example, consumers may not use a more durable product more intensely, but they may use it for a longer time (Koenigsberg et al. 2011). This argument is also supported in White et al. (1999). Hence, we focus on products with low discretionary use.

Environmental impact per-unit time metric, E_k, consists of two main components: $e_u\tau_i$ per unit time use impact and $\frac{e_p+e_d}{\tau_i}$ per unit time production and disposal impacts. Products can be classified based on the phase in which they entail most of their environmental impact: Environmental impact during the use phase dominates (i.e., high $\frac{e_u}{e_p+e_d}$) for some products, such as automobiles, refrigerators, washing machines. In contrast, environmental impact during production and disposal phase dominates (i.e., low $\frac{e_u}{e_p+e_d}$) for some other products, such as carpets, computers. In order to facilitate the discussion, we refer to $\frac{e_u}{e_p+e_d}$ ratio as the relative use impact of a product in the remainder of this section.

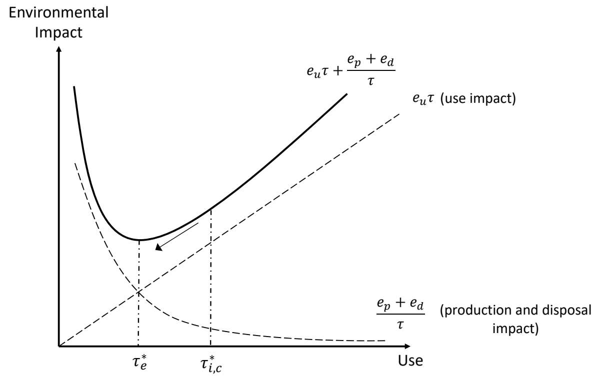


Figure 3 How does servicization improve environmental impact?

From Eq.(8), it is straightforward to show that *environmentally optimum* consumer use durations for both segments are $\tau_e^* = \sqrt{\frac{e_p+e_d}{e_u}}$, when these segments are served by the firm. Therefore, whether servicization can decrease the environmental impact or not critically depends on how it alters the use durations of both segments relative to this optimum level. For example, if the use duration of a segment under selling is higher than this optimum level, i.e., $\tau_{i,c}^* > \tau_e^*$, servicization decreases environmental impact of this segment when it decreases its use duration towards the environmentally optimal level as shown in Figure 3. It is possible that servicization may increase or decrease the environmental impact of the both market segments. It may also move the environmental impact of the two market segments in opposite directions. These outcomes depend on how servicization alters the use durations of each segment relative to environmentally optimum use durations. The following proposition characterizes how consumer use durations change under servicization.

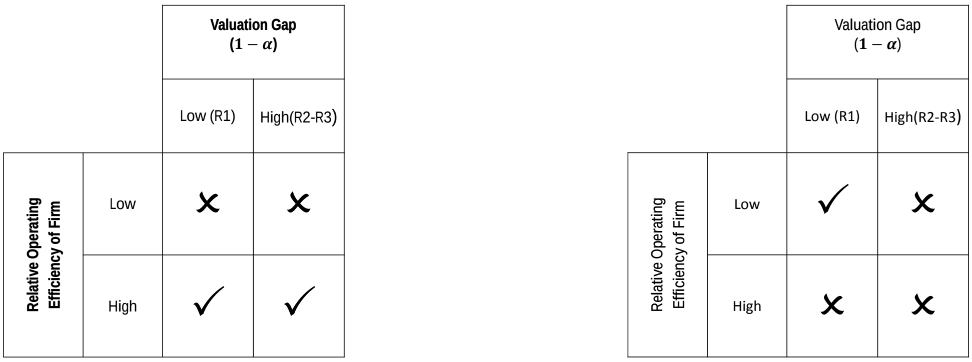
LEMMA 1. *(Use Choices) When servicization is more profitable than selling,*
(i) in R1, servicization increases the use durations of both segments when $r > \sqrt{\frac{\alpha^3(1-\beta)^2}{(\alpha-\beta)\left(\alpha^2-2\alpha\beta+\beta\right)}}$. *It decreases the use durations of both segments when* $\sqrt{\frac{\alpha^2(1-\beta)}{\alpha^2-2\alpha\beta+\beta}} > r$. *Otherwise, when* $\sqrt{\frac{\alpha^3(1-\beta)^2}{(\alpha-\beta)\left(\alpha^2-2\alpha\beta+\beta\right)}} > r > \sqrt{\frac{\alpha^2(1-\beta)}{\alpha^2-2\alpha\beta+\beta}}$, *it increases the use duration of the high end segment but decreases the use duration of low end segment.*
(ii) in R2, servicization always increases the use duration of low end segment. It increases the use duration of high end segment if and only if $r > \sqrt{\frac{1-\beta}{\alpha^2-2\alpha\beta+\beta}}$.
(iii) in R3, servicization always increases the use duration of the high end segment, and does not alter the use duration of low end segment.

Recall that in $R1$ both segments are served in both selling and servicization strategies. Here, there are two factors in play. The servicizing firm increases its desired use durations for each segments as its operating cost per unit use decreases, in other words, as its operating efficiency increases. At the same time, the servicizing firm distorts the offered use duration of the low-end segment downward to achieve segmentation. When the relative operating efficiency of the servicizing firm is high enough, the increase in the use of level of low-end segment due this high efficiency dominates the decrease due to segmentation distortion, and use duration of both segments increases compared to selling. In contrast, when the relative operating efficiency is moderate, distortion in the use duration of low-segment due to segmentation dominates and the use duration of low-end segment decreases while the use duration of high-end segment increases. When the relative operating efficiency is sufficiently low, the use duration of both segments decrease.

In $R2$, the low-end segment is served only in servicization strategy, hence, servicization increases the use duration for this segment. In this region, use duration of high-end segment increases under servicization only if the relative operating efficiency is high enough. The intuition is similar to the one given for $R1$. Finally, in $R3$, the firm serves only the high-end segment under both selling and servicization. Similar to the other two regions, servicization increases the use duration of the high-end segment when the relative operating efficiency of the firm is sufficiently high, specifically higher than 1, and this condition is always satisfied when servicization is more profitable than selling in this region.

We now turn our attention to the environmental impact of servicization and its relationship with the use durations. As explained earlier, servicization can decrease the environmental impact of a consumer segment when it alters the use duration towards the environmentally optimum use duration, i.e., τ_e^*. For example, in R3, servicization always increases the overall use duration as seen in Lemma 1. Therefore, servicization would reduce the environmental impact of this product if, for instance, the use duration under servicization does not exceed the environmentally optimal use duration in this case.

Increasing use duration has opposite effects on two components of the environmental impact as shown in Figure 3. In order to understand the overall change in the environmental impact, we need to compare the changes in use vs. production and disposal impacts. Furthermore, we repeat this analysis for all regions. Comparisons in R1 and R2 regions are more subtle because both segments are served at least in one of the selling and servicization models. In some cases, servicization may decrease the use duration of a segment while increasing the use duration of the other segment. Therefore, understanding the overall effect resulting from both segments requires a more intricate analysis. The result of this analysis is stated in the following proposition. Our goal here is to identify the necessary and sufficient conditions that make servicization a win-win strategy.



(a) Low relative use impact products (b) High relative use impact products

Figure 4 When does servicization improve both profitability and environmental impact?

Proposition 4. *(Win-Win) When servicization is more profitable than selling,*
(i) for low relative use impact products characterized by $\frac{e_u}{e_p+e_d} < \Delta(\alpha, \beta, m_c, m_f)$*, servicization is more environmentally friendly than selling if and only if* $r > \underline{r}(\alpha, \beta)$*.*
(ii) for high relative use impact products characterized by $\frac{e_u}{e_p+e_d} > \Delta(\alpha, \beta, m_c, m_f)$*, servicization is more environmentally friendly than selling if and only if* $r < \overline{r}(\alpha, \beta)$ *and* $1 - \sqrt[4]{\beta} > 1 - \alpha$ *(i.e., equilibrium is in* $R1$*).*
Δ*,* $\underline{r}$*, and* $\overline{r}$ *are piecewise functions and their expressions are stated in the proof of the proposition.*

Figure 4 depicts the conditions characterized in the proposition that makes servicization a win-win proposal. Servicization can lead to a win-win in the case of high relative use impact products only if it can decrease weighted average use duration $\beta\tau^*_{H,f} + (1-\beta)\tau^*_{L,f}$ since these products have a lower environmentally optimal use duration. However, in $R3$, servicization always increases the use duration as shown in Lemma 1. In $R2$, the use duration of the low segment is always increased; the use duration of high segment can decrease when the firm's relative operating efficiency is sufficiently low. However, decreasing the use duration of high segment to compensate the increase in the use duration of the low-segment requires an extremely low relative operating efficiency, which in turn makes servicization unprofitable. In contrast, in $R1$, use duration of the low-segment is distorted downward to achieve segmentation, therefore the firm's relative operating efficiency does not need to be extremely low to decrease the overall use duration and servicization can result in a win-win in this case. Specifically, for high relative use impact products when the firm's relative operating efficiency is sufficiently low, servicization results in a win-win in $R1$, that is, when the valuation gap between high and low segment is sufficiently small.

It is worth noting that servicization's ability to offer customized use durations for each segment assists in reducing the environmental impact of high relative use impact products when valuation gap is low, i.e., in $R1$, as it leads to downward distortion in the low end segment's use duration. In contrast, when the valuation gap is high, i.e., in $R2$, ability to offer customized use durations may lead to market expansion, which in turn may increase the environmental impact.

In the case of low relative use impact products (or in other words high relative production and disposal impact products), servicization can decrease environmental impact only if it can increase their use durations because these products have a higher environmentally optimal use duration. Recall that a higher relative operating efficiency always increases the use durations. Because a higher efficiency also increases profitability, a sufficiently high relative operating efficiency combined with a sufficiently small relative use impact, i.e., $\frac{e_u}{e_p+e_d}$, will both decrease environmental impact and increase profitability. That is, servicization will result in a win-win for low relative use impact products when its relative operating efficiency is above a threshold and the product's relative use impact is below a threshold. Proposition 4 explicitly characterizes these thresholds.

Proposition 4 can also help us identify when servicization can never result in a win-win situation. The following corollary will facilitate our discussion.

Corollary 1. *$\overline{r}(\alpha,\beta) < \underline{r}(\alpha,\beta)$ in $R1$, therefore there exist r such that $\overline{r} < r < \underline{r}$.*

The corollary and Proposition 4 show that unless there is a significant difference in the operating efficiencies of the firm and consumers or in the valuation gap between consumer segments so that r is outside of $(\overline{r}, \underline{r})$ or the equilibrium is not in $R1$, servicization can never decrease the environmental impact.

In summary, we analytically characterized when servicization can be a win-win strategy where it increases firms' profits and simultaneously decreases environmental impact. Our results are contrary to the popular argument that higher product durability decreases the environmental impact.We found that product durability, by itself, does not determine the environmental impact and cannot be a good proxy for it.[2] Product type, valuation gap, and the relative operating efficiency of firm must be all taken into account for determining the environmental impact of servicization. Figure 4 summarizes the environmental performance of servicization as a function of these features. One might also argue that a more durable product should reduce the environmental impact of products with high production and disposal impacts since it may extend the product use duration and spread the production and disposal impacts to a longer time. However, in $R1$, we show that environmental impact may increase for high production and disposal impact products even though servicization

[2] We provide specific examples in Orsdemir et al. (2017) in which servicization increases environmental impact despite resulting in higher product durability.

always increases product durability in this region. In addition, when the firm and consumers have similar operating efficiencies, and consumer segments' valuations are close to each other, servicization can never be environmentally superior. Thus, evaluating whether servicization is an environmentally sound strategy needs careful analysis.

5.2. Welfare implications of servicization

In this section, we investigate the impact of servicization on the consumer surplus (CS), and then characterize when servicization is beneficial for the consumers, the firm and the environment simultaneously. The consumer surplus (CS) is given by

$$CS_c = \sum_{i=L,H} \int_0^{\tau_{i,c}^*} (\theta_i - \frac{t}{\delta})dt - \frac{m_c}{2\delta}\tau_{i,c}^{*2} - p, \tag{9}$$

$$CS_f = \sum_{i=L,H} \int_0^{\tau_{i,v}^*} (\theta_i - \frac{t}{\delta})dt - F_i, \tag{10}$$

for selling in Eq. (9) and for servicization in Eq. (10), where $\tau_{i,c}^*$ and $\tau_{i,f}^*$ show type-θ_i equilibrium use durations in these strategies, respectively. Next proposition compares the CS generated by selling and servicization strategies.

Proposition 5. *(Consumer Surplus) When servicization is more profitable than selling,*
(i) In $R1$, servicization increases the CS if and only if $r > \sqrt{\frac{\alpha^2(1+\alpha)(1-\beta)^2}{2(\alpha-\beta)\left(\alpha^2+\beta-2\alpha\beta\right)}} \triangleq h(\alpha,\beta)$.
In addition, $h > 1$.
(ii) In $R2$, servicization always increases the CS.
(iii) In $R3$, servicization does not alter the CS.

The proposition demonstrates that in $R1$, servicization increases the CS only if servicizing firm has high enough operating efficiency. In fact, the firm's operating cost has to be strictly lower than the consumer operating cost ($h > 1$). Essentially, when the firm can manipulate the use durations of the product, it can extract a higher portion of the consumer utility. This effect can only be overcome if relative operating efficiency of servicization is sufficiently high, i.e., $r > h$. Thus, the proposition shows that, servicization can have a detrimental impact on the CS, when the relative profitability of low-end segment is high enough so that the firm always serves both segments (region $R1$).

In $R2$, servicization always increases the CS. Note that the firm serves only the high end segment under selling strategy in this region. Hence, it extracts the entire consumer surplus. On the other hand, the firm serves both segments under servicization strategy, and the high end segment can still achieve a positive surplus. Recall that this region emerges because the servicizing firm can control the use durations, which enables it to continue to serve the low end segment. Therefore, as opposed to $R1$, where increased control over product use durations has a detrimental effect on consumer surplus,

Strategy	Regions	δ^*	τ^*	π^*
Selling	$R1$, $R2$	$\delta_H^* = \frac{\theta^2}{4k(1+m_c)},\ \delta_L^* = \frac{\left(\alpha^2-\beta\right)\theta^2}{4k(1-\beta)(1+m_c)}$	$\tau_H^* = \frac{\theta\delta_H^*}{1+m_c},\ \tau_L^* = \frac{\alpha\theta\delta_L^*}{1+m_c}$	$\frac{M\left(\alpha^4+\beta-2\alpha^2\beta\right)\theta^4}{16k(1-\beta)(1+m_c)^2}$
	$R3$	$\delta_H^* = \frac{\theta^2}{4k(1+m_c)}$	$\tau_H^* = \frac{\theta\delta^*}{1+m_c},\ \tau_L^* = 0$	$\frac{\theta^4\beta M}{16k(1+m_c)^2}$
Servicization	$R1$, $R2$	$\delta_H = \frac{\theta^2}{4k\left(1+m_f\right)},\ \delta_L = \frac{\theta^2(\alpha-\beta)^2}{4(1-\beta)^2k\left(1+m_f\right)}$	$\tau_H^* = \frac{\theta\delta^*}{1+m_f},\ \tau_L^* = \frac{(\alpha-\beta)\theta\delta^*}{(1-\beta)(1+m_f)}$	$\frac{\theta^4M\left(\alpha^4-4\alpha^3\beta+3\left(2\alpha^2-1\right)\beta^2+(3-4\alpha)\beta^3+\beta\right)}{16(1-\beta)^3k\left(1+m_f\right)^2}$
	$R3$	$\delta_H = \frac{\theta^2}{4k(1+m_f)}$	$\tau_H^* = \frac{\theta\delta^*}{1+m_f},\ \tau_L^* = 0$	$\frac{\theta^4\beta M}{16k(1+m_f)^2}$

Table 3 Equilibrium product durability, use duration and profit when the firm offers a product line.

in $R2$, utilizing use durations in pricing increases the CS. Finally, in $R3$, since the firm serves only the high end segment under both strategies, the CS is always zero. Overall, when servicization and selling have the same operating efficiency, servicization improves the CS, only if it extends the market coverage.

Finally, we characterize when servicization is more beneficial for the firm, the environment and the consumers simultaneously so that it leads to a win-win-win outcome.

PROPOSITION 6. *(Win-Win-Win) Servicization can be a win-win-win strategy only for low relative use impact products characterized by* $\frac{e_u}{e_p+e_d} < \Delta(\alpha, \beta, m_c, m_f)$*. This happens if and only if the equilibrium is in* $R1$ *and* $r > h(\alpha, \beta)$*, or in* $R2$*.* Δ *is defined in the proof of Proposition 4 and* h *is defined in Proposition 5.*

The proposition combines Propositions 4 and 5 to show servicization can be a win-win-win strategy only for the low relative use impact products. For the high relative use impact products, it results in a worse outcome in at least one of these dimensions, thus, never achieves a win-win-win outcome.

6. Extensions

We extend our model by allowing the firm to offer a product line in §6.1 and to use a hybrid strategy in §6.2. In §6.3, we discuss some of our modelling assumptions and provide additional extensions.

6.1. Product line

In the base model, we assume that the firm offers a single product via selling or servicization. We now study what happens when the firm can offer a product line. Specifically, we allow the firm to design two products with different durabilities under both selling and servicization. For example, Interface sells carpets made of type 6 and type $6, 6$ fiber, where type $6, 6$ is known to be more durable. We denote high and low product durabilities with δ_H and δ_L, respectively. Next proposition describes the equilibrium for selling and servicization strategies.

PROPOSITION 7. *Suppose the firm can design two products with different durabilities. The following characterizes the equilibrium. The optimum product durability, product use and firm profits are provided in Table 3.*

($R1^{pl}$) *When* $\frac{1}{\alpha} \leq \frac{\alpha}{\beta}$*, the firm serves both segments under both selling and servicization strategies.*

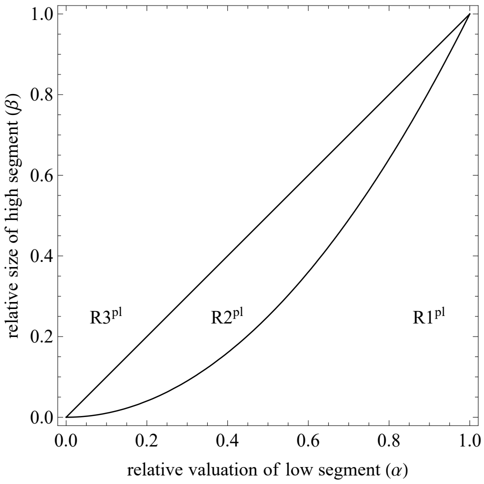


Figure 5 Equilibrium regions when the firm offers a product line.

$(R2^{pl})$ *When* $1 < \frac{\alpha}{\beta} < \frac{1}{\alpha}$*, the firm serves high valuation segment under selling strategy and both segments under servicization strategy.*
$(R3^{pl})$ *When* $\frac{\alpha}{\beta} \leq 1$*, the firm serves only high valuation segment under both selling and servicization strategies.*

Figure 5 demonstrates the equilibrium regions. The equilibrium structure is akin to the single product case. That is, it depends on the relative profitability of low-end segment, i.e., $\frac{\alpha}{\beta}$. As we move from $R1^{pl}$ to $R3^{pl}$, serving the low-end segment becomes less attractive and the firm stops serving low-end segment when the $\frac{\alpha}{\beta}$ is sufficiently small. Similar to the base model, the servicizing firm is still more likely to serve low end segment compared to the selling firm. By comparing Propositions 1 and 7, we can observe that the region where servicization leads to market expansion is much larger in product line model compared to single product model since ability to tailor product durabilities further enhances the segmentation ability of servicization.

To see how servicization impacts the product durabilities, we need a metric that would allow us to compare the durabilities. To that end, we define average durability as

$$\bar{\delta_j} = \frac{\beta\delta^*_{H,j} + (1-\beta)\delta^*_{L,j}}{\beta + (1-\beta)1_{\{\delta^*_{L,j}>0\}}} \qquad j = c, f,$$

where we set $\delta^*_{L,j} = 0$ when low segment is not served. This is similar to the average quality metric used in Netessine and Taylor (2007). Next proposition compares the average product durabilities under selling and servicization strategies.

Proposition 8. *Suppose the firm can design two products with different durabilities. When servicization is more profitable than the selling strategy, servicization increases the average product durability over selling except when* $r < \frac{1-\beta}{\alpha^2+\beta-2\alpha\beta}$ *in* $R2^{pl}$*. Furthermore,* $\frac{1-\beta}{\alpha^2+\beta-2\alpha\beta} > 1$.

The impact of servicization on product durability remains similar to our base model (see Proposition 3). Servicization can decrease the average product durability when a larger consumer base is served. In fact, the threshold on r in $R2^{pl}$ is same as the one in $R2$ of our base model. In the base model when the servicizing firm serves to both segments, it designs the product for an *average* consumer. In this case if both segments are served, the durability in the base model is equal to the *average* durability in the product line model. Thus, comparison of product durabilities under different strategies, in $R2$ in the base model, and in $R2^{pl}$ in the product line model, leads to the same threshold. It is worth noting that although the expressions of thresholds are same in both propositions, they arise in different regions, i.e., $R2 \neq R2^{pl}$.

Finally, we investigate the impact of servicization on environmental impact for the product line model. The next proposition shows that for $R2^{pl}$ and $R3^{pl}$, our results are similar to the base model. In particular, when the valuation gap is high enough such that the equilibrium falls into one of these regions, servicization is a win-win strategy only for low relative use impact products.

PROPOSITION 9. *Suppose that the equilibrium is in $R2^{pl}$ or $R3^{pl}$. Then, when servicization is more profitable than selling, it is also more environmentally friendly than selling if and only if the product is a low relative use impact product characterized by $\frac{e_u}{e_p+e_d} < \Delta^{pl}(\alpha, \beta, m_c, m_f)$, and $r > \underline{r}^{pl}(\alpha, \beta)$. Δ^{pl}, $\underline{r}^{pl}$ are piecewise functions and their expressions are stated in the proof of the proposition.*

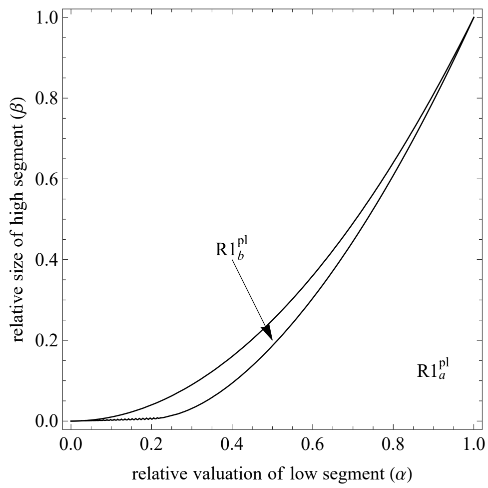


Figure 6 **Servicization can be environmentally friendly for both high and low relative use impact products in $R1_a^{pl}$ and only for low use impact products in $R1_b^{pl}$.**

Finally, Figure 6 helps us characterize the impact of servicization on environmental in $R1^{pl}$. Note that the characterizations of $R1_a^{pl}$ and $R1_b^{pl}$ require only two outside parameters, α and β. Thus, this figure describes the outcome for all possible parameter choices. In $R1_a^{pl}$ servicization can be more

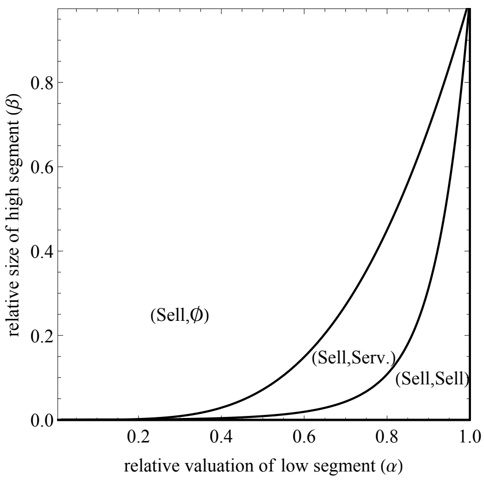


Figure 7 **Equilibrium regions when the firm can use a hybrid strategy. In (i,j), i denotes the strategy used for the high end segment and j denotes the strategy used for the low end segment. $\emptyset$ means the segment is not served ($\theta=2, k=0.1, M=1, m_c=0.10, m_f=0.11$).**

environmentally friendly for both product types. However, in $R1_b^{pl}$, it can be more environmentally friendly only for low relative use impact products.[3] Combined with Proposition 9, this result shows that for a sufficiently low valuation gap servicization can be environmentally superior for both low and high relative use impact products. Otherwise, it can be environmentally superior only for low relative use impact products. Thus, our results show that servicization can result in a win-win outcome for both product types even when the firm is allowed to offer a product line. One exception worth mentioning is that in the product line model, servicization may cease to become environmentally superior for high relative use impact products when both segments are served, i.e., in $R1_b^{pl}$, whereas in the base model there always exist $e_u/(e_p+e_d)$ and r values that make servicization more environmentally friendly for high relative use impact products when both segments are served, i.e., in $R1$.

6.2. Hybrid Strategy

We now extend our base model to allow the firm to use a hybrid strategy. In a hybrid strategy, the firm can utilize both selling and servicization strategies at the same time. The next proposition shows when and how the firm implements a hybrid strategy.

Proposition 10. *A hybrid strategy is optimal if and only if $\gamma(\alpha,\beta) \leq \frac{\alpha}{\beta}$ and $m_c < m_f < m_1(\alpha,\beta,m_c)$. In this case, the firm serves the high end segment with selling strategy and the low end segment with servicization strategy. m_1 is stated in the proof of the proposition.*

[3] We explicitly characterize the threshold $e_u/(e_p+e_d)$ ratios that define low and high relative use impact products and describe the impact of r on our results in online Appendix B.

Recall that γ is characterized in the proof of Proposition 1. Figure 7 demonstrates the equilibrium regions that emerge when the firm utilize a hybrid strategy as a function of α and β. The figure indicates that hybrid strategy is attractive when the valuation gap is neither too low nor too high. Furthermore, the relation between the operating cost stated in the proposition indicates that r should not be too small but $r < 1$. Therefore, when the firm's operating efficiency is lower than consumers (but not too low), it prefers a hybrid strategy. Otherwise, the firm uses only the pure strategies as described in Proposition 2. We next investigate the impact of the hybrid strategy on product durability.

PROPOSITION 11. *When the hybrid strategy is optimal, it always increases product durability compared to the pure selling strategy in* $R1$ *and always decreases product durability compared to the pure selling strategy in* $R2$.

Recall from Proposition 3 that pure servicization always increases product durability as long as the same consumer segments are served under pure selling and pure servicization. Otherwise, product durability may decrease with servicization. Proposition 11 shows that a similar result holds when servicization is offered through a hybrid strategy.

Next we compare the environmental impact of hybrid strategy to that of pure selling.

PROPOSITION 12. *When the hybrid strategy is optimal, it always increases the environmental impact in* $R2$. *However, in* $R1$,
(i) for low relative use impact products characterized by $\frac{e_u}{e_p+e_d} < \Delta_h(\alpha,\beta,m_f,m_c)$, *hybrid strategy is more environmentally friendly than pure selling if and only if* $m_f < m_2(\alpha,\beta,m_c)$, $\alpha < 1/2$ *and* $\beta < \beta_1(\alpha)$.
(ii) for high relative use impact products characterized by $\frac{e_u}{e_p+e_d} > \Delta_h(\alpha,\beta,m_f,m_c)$, *hybrid strategy is more environmentally friendly than pure selling if and only if* $m_f > m_3(\alpha,\beta,m_c)$.
β_1 *and* m_3 *are piecewise continuous functions. The characterization of* β_1, m_2, m_3 *and* Δ_h *are stated in the proof of the proposition.*

The fundamental difference between Proposition 4 and Proposition 12 is that if servicization is offered through a hybrid strategy, it ceases to become environmentally superior for all types of products when it leads to market expansion. Recall from Proposition 4 that pure servicization can be environmentally superior for low relative use impact products even after market expansion.

6.3. Additional Extensions and Discussion of Model Assumptions

In this section, we discuss some of our modeling assumptions and provide additional extensions. Here, we will provide a brief summary, the analyses and more detailed discussions of these extensions are available in Orsdemir et al. (2017).

We consider two consumer segments in our model. We are able to show that our results continue to hold with three consumer segments. Furthermore, we find that servicization may result in a larger market expansion with three segments.

We assume that marginal operating cost increases with the product use and furthermore the rate of increase depends on the durability of the product. We are able to show the robustness of our results under various alternative operating cost assumptions. For example, we consider a constant marginal operating cost and we allow operating cost to be independent of product durability. In addition to showing that our key results remain intact, we find that the correlation between operating cost and product durability induces the firm to choose a higher product durability. Finally, we can allow operating cost to be uncertain for consumers. Our main insights continue to hold in this case. Moreover, we observe that increasing cost uncertainty results in a higher market coverage by the firm.

The selling firm does not offer after-sales-support. If we allow the selling firm to offer after-sales-support, the firm would charge cost of the after-sales-support to the consumers through its contract offer. Therefore, this model would resemble a servicization model to the extent that the firm can capture after-sales-support market. However, in many cases, after-sales-support market can be very competitive due to the existence of third party vendors (for carpets, for instance, a large number of carpet cleaning companies exist) and "some OEMs are content to let independent service providers cater to customers" (Cohen et al. 2006). Therefore, our model would be applicable in many of these scenarios.

Finally, we do not consider resource pooling in our model that may be an option in some examples of servicization. However, resource pooling is not feasible in many other cases such as carpet manufacturing. We also do not consider product recovery options such as remanufacturing and recycling, which may raise the value of servicization. These issues can be studied in future research.

7. Concluding Remarks

In this paper, we study when servicization can be a win-win strategy where it increases the firm's profits and *simultaneously* decreases its environmental impact. Even though there exists anecdotal evidence that servicization has the potential to achieve these outcomes, very limited analysis has been conducted in prior literature to identify when this can happen. In order to study whether this claim holds, we build models for both selling and servicization strategies for the firm. In our model, the firm either sells a product or provides a product through servicization to a market consisting of two consumer segments with different valuations for product use. Product durability decision for the firm is endogenously determined in both models. In the selling model, consumers make a purchase decision and incur an operating cost based on their endogenously determined use duration of the product. In the servicization model, the firm can screen the consumers by offering a menu of contracts that specifies a price and a use duration, and the firm incurs the operating cost of the product. Thus, some of the key features of our model are: a market with heterogeneous consumer segments; endogenously determined product use durations by consumers in each market segment; and endogenously determined prices and product durability by the firm.

We show that whether servicization can be a win-win strategy critically depends on the product type, the relative operating efficiency of the firm compared to consumers, and the valuation gap between the consumer segments. For products that have low use impact relative to their production and disposal impacts, servicization can be more environmentally friendly and profitable if the firm has higher operating efficiency relative to consumers. On the other hand, for products that have high use impact relative to their production and disposal impacts, servicization can be more environmentally friendly and profitable only if the firm has a lower relative operating efficiency and the valuation gap between the consumer segments is low.

We also find that the ability to screen the consumer segments under servicization can adversely affect its environmental impact. This is because servicization may increase the environmental impact for both low relative use and high relative use impact products. In fact, this ability may also hurt the social surplus because, under servicization, the firm may offer a very inefficient use duration to the low end segment in order to achieve segmentation. Appendix A in online supplement illustrates this result. Therefore, the social surplus may decrease even when the firm is more efficient in operating the product than consumers.

Another commonly held belief is that servicization increases product durability and, thus, decreases the environmental impact. This is because, under servicization, firms incur the operating cost of product. We show that servicization indeed leads to a higher product durability when the firm serves the same consumer segments under selling and servicization strategies. However, when the firm targets additional consumer segments under servicization, product durability may be lower than that of the selling strategy. In addition, our results indicate that product durability is not a good proxy for the environmental impact of a product. To evaluate the environmental benefits of servicization, one needs to consider product type, relative operating efficiency of firm, and the valuation gap between the consumer segments.

Our work offers one potential explanation for why the servicization experiment at Interface may have failed (Oliva and Quinn 2003). It has been popularly hypothesized that the Interface experiment may have failed because the cost of operating the product (janitorial services) was much higher for the firm (Interface carpets) than the customer (University of Texas). Our analysis shows that this may not necessarily be the case. Our model shows that the primary reason why the servicization experiment may have failed at Interface may be the inability to segment the customer segments by offering different service contracts to different customer segments.

Thus, some of the key practical takeaways from our analysis are as follows: For servicization to be successful in the market, the servicization contract needs to be tailored to the unique needs of each customer segment. For servicization to be a win-win strategy for a firm, it needs to carefully examine its market segments, as well as understand its operating efficiency relative to that of its customers. If the valuation gap between the customer segments in the market is high, then, for firms who sell products which have a low environmental impact during the use phase of the product life-cycle compared to the production and disposal phases, the firm should focus on improving its operating efficiency in order for servicization to be a win-win strategy. Also, if the valuation gap between the customer segments is high, then, for firms who sell products which have a high environmental impact during the use phase of the product life-cycle should not embrace servicization. If the consumer segments are more or less homogeneous, servicization can be a win-win strategy for the firm for both high use impact and low use impact products, provided that the firm adjusts the durability of the product appropriately. Thus, while servicization as a business strategy holds promise it should be implemented with care.

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Online Supplement to "Is Servicization a Win-Win Strategy? Profitability and Environmental Implications of Servicization"

In this online supplement, we study social surplus (SS) in Appendix A, provide characterization of thresholds that appear in Section 6.1 in Appendix B and provide the proofs of the analytical results in Appendix C in the order their corresponding results appear in the paper.

A. Social Surplus

In this section, we investigate the impact of servicization on SS. The SS is the sum of the firm's profit and consumer surplus (CS), and it is important in analyzing the overall efficiency of servicization.

PROPOSITION 13. *(Social Surplus) When servicization is more profitable than the selling strategy, servicization increases SS except when $r < k_1(\alpha, \beta)$ in R1. Furthermore, $k_1(\alpha, \beta) > 1$ if and only if $1 - \sigma(\beta) > 1 - \alpha$. The expressions for k_1 and σ are explicitly characterized in the proof of the proposition.*

Intuition suggests that whenever the firm's operating cost is smaller than those of consumers ($r > 1$), the servicization should improve the SS because shifting the operating cost burden to the firm should improve overall efficiency in the system. However, contrary to this intuition, Proposition 13 shows that servicization may decrease the SS even when the firm has a better operating efficiency than the consumers. This happens when the firm serves both segments under both selling and servicization and the valuation gap between the segments is low, i.e., $1 - \sigma(\beta) > 1 - \alpha$. This result indicates that the social planner may prefer selling over servicization even when consumers have an inferior operating efficiency. This outcome is due to two factors: product durability choice and consumer use durations under selling and servicization strategies. To the extent that the product design, i.e., product durability, and the consumer use durations are close to the *socially optimum*[1], servicization would improve the social surplus. On one hand, when servicization is chosen, the firm's product durability choice in $R1$ is always closer to the socially optimum compared to firm's product durability choice under selling in the same region. On the other hand, the servicizing firm distorts the use duration offered to the low-end segment away from the socially optimum level to make this option less attractive for high segment, so it can charge a higher price to the high-end segment. In some cases, this distortion may be too high and make low end segment's offered use duration socially worse than the segment's use duration under selling strategy. These observations are summarized in the following lemma.

LEMMA 2. *When servicization is more profitable than the selling strategy, in $R1$,*
(i) product durability choice under servicization is always closer to the socially optimum level relative to the product durability choice under selling strategy.
(ii) for a given product durability, low end segment's use duration under selling strategy is always closer to

[1] The firm's contracting problem leads to socially optimum outcome when there is no information asymmetry, i.e., consumer types are common knowledge (Netessine and Taylor 2007, cf. Laffont and Martimort 2009 Ch. 2) and the firm can charge different prices to different consumer segments. The characterization of this case is given in Orsdemir et al. (2017).

the socially optimum use duration relative to the low end segment's use duration under servicization if and only if $r < \frac{\alpha^2(1-\beta)}{\alpha^2+\beta-2\alpha\beta}$. *Furthermore,* $\frac{\alpha^2(1-\beta)}{\alpha^2+\beta-2\alpha\beta} > 1$.

Because the firm determines product durability based on low-end segment's valuation in $R1$ in the case of selling (as explained in §4.3), as the gap between segment valuations widens, i.e., $1-\alpha$ gets larger, product durability moves further away from the social optimum, and servicization becomes more socially preferable. On the other hand, when the gap between the segments is low, i.e., $1-\alpha < 1-\sigma(\beta)$, product durability under selling is not too far from the social optimum, and the inefficient use duration of low end segment under servicization dominates. Therefore, servicization may lead to a lower social surplus even when the firm has a better operating efficiency than the consumers.

In region $R2$, a servicizing firm serves more consumer segments than a selling firm, that is, the low-end segment is served only by the servicizing firm. The high end segment can capture positive consumer surplus. Thus, servicization always results in a higher social surplus in $R2$ as long as it is more profitable. In region $R3$, only the high end segment is served in both cases. Therefore, the consumer surplus is always zero, and the social surplus is equal to firm's profit. In this region, servicization increases the social surplus, when it is more profitable.

B. Characterization of thresholds in Section 6.1:

The next proposition characterizes when servicization can be a win-win strategy in $R1_a^{pl}$ and $R1_b^{pl}$. Recall that $R1^{pl} = R1_a^{pl} \cup R1_b^{pl}$.

Proposition 14. *In* $R1$, *servicization is a win-win strategy only if* $r > \frac{(\beta-1)^2\left(\alpha^4-2\alpha^2\beta+\beta\right)}{\alpha^4-4\alpha^3\beta+3(2\alpha^2-1)\beta^2+(3-4\alpha)\beta^3+\beta}$, *and*
(i) when $U_f^{pl} < U_c^{pl}$ *and* $D_f^{pl} > D_c^{pl}$, $\frac{e_u}{e_p+e_d} > \Delta_{R1}^{pl}(\alpha,\beta,m_c,m_f)$.
(ii) when $U_f^{pl} > U_c^{pl}$ *and* $D_f^{pl} < D_c^{pl}$, $\frac{e_u}{e_p+e_d} < \Delta_{R1}^{pl}(\alpha,\beta,m_c,m_f)$.
(iii) when $U_f^{pl} < U_c^{pl}$ *and* $D_f^{pl} < D_c^{pl}$.
Furthermore, $U_f^{pl}, U_c^{pl}, D_f^{pl}$ *and* D_c^{pl} *are defined in the proof of the propositon.*

C. Proofs

Proof of Proposition 1: We first solve the equilibrium for selling strategy, then we solve it for servicization strategy. In selling strategy, if type-θ_i purchases the product, it uses the product for $\tau_i = \frac{\delta\theta}{1+m_c}$. Then, $U_c(\theta_i) = \frac{\delta\theta_i^2}{2(1+m_c)} - p$. If the firm sells to both segments, $p = \frac{\delta\theta_L^2}{2(1+m_c)}$; otherwise, $p = \frac{\delta\theta_H^2}{2(1+m_c)}$. It is easy to see that when these prices are plugged into firm's profit function, the function becomes concave in product durability δ. Thus, from the first order conditions: If the firm serves both segments, product durability is $\delta^* = \frac{\alpha^2\theta^2}{4k(1+m_c)}$; otherwise, $\delta^* = \frac{\theta^2}{4k(1+m_c)}$. The firm profits are $\pi_{c,B} = \frac{\alpha^4 M\theta^4}{16k(1+m_c)^2}$, $\pi_{c,H} = \frac{\beta^4 M\theta^4}{16k(1+m_c)^2}$, respectively. Therefore, the firm serves both segments if and only if $\alpha > \sqrt[4]{\beta}$.

In servicization, if the firm serves both segments, one can show that at the equilibrium, IR_H and IC_L constraints do not bind, but IR_L and IC_H bind. Hence, $F_L = \tau_L\left(\theta_L - \frac{\tau_L}{2\delta}\right)$ and $F_H = \tau_H\left(\theta_H - \frac{\tau_H}{2\delta}\right) - \tau_L\left(\theta_H - \frac{\tau_L}{2\delta}\right) + F_L$. When we plugged in these to the profit function, we have $\pi_{f,B}(.|F_H,F_L) = M\left(-k\delta^2 + b\theta_H\left(\tau_H - \tau_L\right) + \theta_L\tau_L\right) - \frac{(1+m)M\left(b\tau_H^2-(-1+b)\tau_L^2\right)}{2\delta}$. This function is concave in τ_H, then from FOC, $\tau_H = \frac{\delta\theta_H}{1+m_f}$. After incorporating this expression to the profit function, we obtain $\pi_{f,B}(.|F_L,F_H,\tau_H) =$

$-M\left(k\delta^2+\beta\theta_H\tau_L-\theta_L\tau_L\right)+\frac{M\beta\delta\theta_H^2}{2+2m_f}+\frac{M(-1+\beta)\left(1+m_f\right)\tau_L^2}{2\delta}$. This is concave in τ_L; hence, τ_L can be found as $\frac{\delta(\beta\theta_H-\theta_L)}{(-1+\beta)\left(1+m_f\right)}$. Note that $\tau_L>0$ if and only if $\alpha>\beta$. After plugging this in, δ can be found as $\frac{\left(\alpha^2+\beta-2\alpha\beta\right)\theta^2}{4k\alpha^2(-1+\beta)\left(1+m_f\right)}$, similarly. When the firm serves only the high-end segment, only IR_H binds and the equilibrium can be obtained similar to the selling model.

Under servicization, the firm serves both segments if and only if $\pi_{f,B}\geq\pi_{f,H}$. One can show that $\lim_{\alpha\to 1}\frac{\pi_{f,B}}{\pi_{f,H}}>1$, $\lim_{\alpha\to\beta}\frac{\pi_{f,B}}{\pi_{f,H}}<1$, and $\frac{\pi_{f,B}}{\pi_{f,H}}$ is increasing in α when $\alpha\in(\beta,1)$. Therefore, there is only one threshold α_t where $\frac{\pi_{f,B}(\alpha_t(\beta))}{\pi_{f,H}(\alpha_t(\beta))}=1$. Define $\gamma(\alpha,\beta)=\frac{\alpha_t(\beta)}{\beta}=\gamma(\alpha,\beta)$. It can be shown that at $\alpha=\sqrt[4]{\beta}$, serving to both segment is more profitable. Hence, $\gamma(\alpha,\beta)<\sqrt[4]{\beta}$. □

Proof of Proposition 2: In R1, $\frac{\pi_{f,B}}{\pi_{c,B}}>1$ if and only if $\frac{M\left(\alpha^2+\beta-2\alpha\beta\right)^2\theta^4}{16k(-1+\beta)^2\left(1+m_f\right)^2}>\frac{M\alpha^4\theta^4}{16k(1+m_c)^2}$. This can be rearranged to show that $\frac{\pi_{f,B}}{\pi_{c,B}}>1$ if and only if $r>\frac{\alpha^2(1-\beta)}{\alpha^2+\beta-2\alpha\beta}\triangleq f_1$. Simple algebra shows that $f_1<1$. The the other parts can be shown similarly. □

Proof of Proposition 3: We only show the proof for region $R2$. The rest can be shown similarly. In R2, $\delta_f^*=\frac{(\alpha^2+\beta-2\alpha\beta)\theta^2}{4k(1-\beta)(1+m_f)}$ and $\delta_c^*=\frac{\theta^2}{4k(1+m_c)}$. We can rearrange the terms and find that product durability is higher under servicization if and only if $r>\frac{1-\beta}{\alpha^2+\beta-2\alpha\beta}\triangleq r_\delta$. We compare this with the minimum operating efficiency threshold above which servicization is more profitable than selling, i.e., $f_1=\frac{\alpha^2(1-\beta)}{\alpha^2+\beta-2\alpha\beta}$. $r_\delta>f_1$ if and only if $1>\alpha^2$ which is true by assumption. $\frac{\partial r_\delta}{\partial\alpha}<0$ for $\alpha\in(\beta,1)$ and $\lim_{\alpha\to 1}r_\delta>1$. Hence $r_\delta>1$. □

Proof of Lemma 1: In $R1$, $\tau_{H,f}>\tau_{H,c}$ if and only if $r>\sqrt{\frac{\alpha^2(1-\beta)}{\alpha^2-2\alpha\beta+\beta}}$. Similarly, $\tau_{L,f}>\tau_{L,c}$ if and only if $r>\sqrt{\frac{\alpha^3(\beta-1)^2}{(\alpha-\beta)(\alpha^2-2\alpha\beta+\beta)}}$. One can show that $\sqrt{\frac{\alpha^3(\beta-1)^2}{(\alpha-\beta)(\alpha^2-2\alpha\beta+\beta)}}>\sqrt{\frac{\alpha^2(1-\beta)}{\alpha^2-2\alpha\beta+\beta}}>f_1$, where f_1 is the thresholds above which servicization is more profitable and it is defined in the proof of Proposition 2. This proves the first part of the proposition. The other parts can be proved similarly. □

Proof of Proposition 4: First define total use duration (total disposal per unit of time) under selling when the firm serves both segments and only the high end segment as U_c^B (D_c^B) and U_c^H (D_c^H), respectively. U_f^B (D_f^B) and U_f^H (D_f^H) are defined similarly for servicization. In what follows, we characterize when servicization decreases the environmental impact for each region, $R1$, $R2$ and $R3$. To do so, we first analyze how the use impact and the production and disposal impact changes as a function of relative operating efficiency in each region. This allows us to find the critical relative operating efficiency values that determine whether the use, and the production and disposal impact increase/decrease under servicization.

In $R1$, product use impact under servicization is $e_u\frac{M\alpha\left(\alpha^2+\beta-2\alpha\beta\right)\theta^3}{4k(1-\beta)\left(1+m_f\right)^2}=e_uU_f^B$ and under selling is $e_u\frac{M\alpha^2(\alpha+\beta-\alpha\beta)\theta^3}{4k(1+m_c)^2}=e_uU_c^B$. Then, use impact under servicization is smaller than under selling strategy if and only if $r<\sqrt{\frac{\alpha(1-\beta)(\alpha+\beta-\alpha\beta)}{\alpha^2+\beta-2\alpha\beta}}\triangleq g_1$. Product disposal and production impact under servicization is $(e_d+e_p)\frac{4kM(1-\beta)(1+(-2+\alpha)\beta)\left(1+m_f\right)^2}{(\alpha-\beta)(\alpha^2+\beta-2\alpha\beta)\theta^3}=(e_p+e_d)D_f^B$ and under selling is $(e_d+e_p)\frac{4kM(1+(-1+\alpha)\beta)(1+m_c)^2}{\alpha^3\theta^3}=(e_p+e_d)D_c^B$. Hence, production and disposal impact is lower under servicization if and only if $r>\sqrt{\frac{\alpha^3(1-\beta)(1+(-2+\alpha)\beta)}{(\alpha-\beta)(1+(-1+\alpha)\beta)(\alpha^2+\beta-2\alpha\beta)}}\triangleq g_2$.

We now show that $g_2>g_1$. $\frac{g_2}{g_1}>1$ if and only if $\frac{\alpha^2(1+(-2+\alpha)\beta)}{(\alpha-\beta)(1+(-1+\alpha)\beta)(\alpha+\beta-\alpha\beta)}>1$. This can be rewritten as $(-1+\alpha)^2(1+\alpha-\beta)\beta^2>0$. Because in this region $\alpha>\beta$, the result follows. We now show that $g_1>f_1$. Recall that f_1 is the threshold that determines when servicization is more profitable than selling (see Proposition 2). First, define $j_1\triangleq\left(\alpha-2\alpha^2-5\alpha^3+11\alpha^4-\alpha^5-\alpha^6\right)\beta^2+\left(1-6\alpha+12\alpha^2-8\alpha^3\right)\beta^3$ and $j_2\triangleq 3\alpha^5-2\alpha^6+$

$(3\alpha^3-6\alpha^4-3\alpha^5+3\alpha^6)\beta$. $\frac{g_1}{f_1}>1$ if and only if $j\triangleq j_1+j_2>0$. $\frac{\partial^3 j}{\partial\beta^3}=-6(-1+2\alpha)^3$ and it is greater than 0 if and only if $\alpha<1/2$. Hence, $\frac{\partial^2 j}{\partial\beta^2}$ has its minimum at $\alpha=\frac{1}{2}$, and it is $\frac{1}{32}>0$. This proves that $\frac{\partial^2(j)}{\partial\beta^2}$ is always positive. Furthermore, $j(\beta=\alpha)=-(-1+\alpha)^3\alpha^3(2+\alpha+\alpha^2)>0$ and $j(\beta=0)=(3-2\alpha)\alpha^5>0$, which proves that $j>0$. Therefore, $g_2>g_1>f_1$. This shows that the following regions exist: 1) A region in which servicization decreases the total use impact but increases the production and disposal impact, i.e., $f_1<r<g_1$. 2) A region in which servicization increases the total use impact but decreases the production and disposal impact, i.e., $r>g_2$.

Let $\Delta_1=\frac{D_c^B-D_f^B}{U_f^B-U_c^B}$. We now show that in $R1$, for low relative use impact products characterized by $\frac{e_u}{e_p+e_d}<\Delta_1$, the necessary and sufficient condition for servicization to decrease the environmental impact and increase the profit is $r>g_2$. We know that $r>g_2$ if and only if $D_c^B>D_f^B$ and $U_c^B<U_f^B$. Therefore, $\frac{e_u}{e_p+e_d}<\Delta_1$ if and only if $e_uU_f^B+(e_p+e_d)D_f^B<e_uU_c^B+(e_p+e_d)D_c^B$. In addition, $\frac{e_u}{e_p+e_d}<\Delta_1$ defines a non-empty set since $\Delta_1>0$ in this region, and $r>g_2$ implies that $r>f_1$. Thus, the result follows.

We now show that in $R1$, for high relative use impact products characterized by $\frac{e_u}{e_p+e_d}>\Delta_1$, the necessary and sufficient condition for servicization to decrease the environmental impact and increase the profit is $f_1<r<g_1$. We know that $r<g_1$ if and only if $D_c^B<D_f^B$ and $U_c^B>U_f^B$. Therefore, $\frac{e_u}{e_p+e_d}>\Delta_1$ if and only if $e_uU_f^B+(e_p+e_d)D_f^B<e_uU_c^B+(e_p+e_d)D_c^B$. In addition, $\frac{e_u}{e_p+e_d}<\Delta_1$ defines a non-empty set since $\Delta_1>0$ in this region, and $f_1<g_1$. Thus, the result follows.

For $R1$, finally, note that when $g_1\le r\le g_2$, $U_f^B\ge U_c^B$ and $D_f^B\ge D_c^B$, and hence, servicization can never improve the environmental impact regardless of the product type.

In R2, under servicization, product use impact, and production and disposal impact are same as in $R1$. Under selling, product use impact is $e_u\frac{M\beta\theta^3}{4k(1+m_c)^2}=e_uU_c^H$. Use impact under servicization is lower if and only if $e_u\frac{M\beta\theta^3}{4k(1+m_c)^2}>e_u\frac{M\alpha\left(\alpha^2+\beta-2\alpha\beta\right)\theta^3}{4k(1-\beta)\left(1+m_f\right)^2}$. This can be reorganized as $r<\sqrt{\frac{(1-\beta)\beta}{\alpha(\alpha^2+\beta-2\alpha\beta)}}\triangleq g_3$. Under selling, product production and disposal impact is given by $(e_d+e_p)\frac{4kM\beta(1+m_c)^2}{\theta^3}$. Then, production and disposal impact under servicization is lower than under selling if and only if $r>\sqrt{\frac{(1-\beta)(1+(-2+\alpha)\beta)}{(\alpha-\beta)\beta(\alpha^2+\beta-2\alpha\beta)}}\triangleq g_4$.

We now show that $g_4>f_2>g_3$. $g_4>f_2$ (see Proposition 2 for f_2) if and only if $\frac{(1-\beta)(1+(-2+\alpha)\beta)}{(\alpha-\beta)\beta(\alpha^2+\beta-2\alpha\beta)}>\sqrt{\frac{(1-\beta)^2\beta}{(\alpha^2+\beta-2\alpha\beta)^2}}$. By taking the square of both sides, the expression can be rewritten as $\alpha^2(1-\beta)^3\beta^2-2\alpha(1-\beta)^3\beta(-1+\beta+\beta^2)+(1-\beta)^3(1-3\beta+\beta^2+\beta^3+\beta^4)>0$. The expression is strictly convex in α and has its minimum at $\alpha=1-\frac{1}{\beta}+\beta<\beta$. Therefore, if the expression is positive at $\alpha=\beta$, it is always positive in $R2$. The value of the expression at $\alpha=\beta$ is $(-1+\beta)^6>0$. $f_2>g_3$ if and only if $f_2^2-g_3^2=\frac{\left(\alpha^2-\beta\right)(-1+\beta)^2\beta}{\alpha^2(\alpha^2+\beta-2\alpha\beta)^2}>0$. Thus, it is enough to show that in $R2$, $\alpha>\sqrt{\beta}$. In order to show this, we will prove that at $\frac{\pi_{f,B}}{\pi_{f,H}}|_{\beta=\alpha^2}<1$. $\frac{\pi_{f,B}}{\pi_{f,H}}|_{\beta=\alpha^2}=\frac{\left(2\alpha^2-2\alpha^3\right)^2}{\alpha^2(-1+\alpha^2)^2}<1$ if and only if $(-1+\alpha)^3\alpha^2(1+3\alpha)<0$, which indeed holds. Thus, $\gamma>\sqrt{\beta}$, and we have $\alpha>\sqrt{\beta}$ in $R2$. Therefore, $g_4>f_2>g_3$. This shows that a region in which servicization increases the total use impact but decreases the production and disposal impact exists, i.e., $r>g_4$.

Let $\Delta_2=\frac{D_c^H-D_f^B}{U_f^B-U_c^H}$. We now show that for low relative use impact products characterized by $\frac{e_u}{e_p+e_d}<\Delta_2$, the necessary and sufficient condition for servicization to decrease the environmental impact and increase the profit is $r>g_4$. We know that $r>g_4$ if and only if $D_c^H>D_f^B$ and $U_c^H<U_f^B$. Therefore $\frac{e_u}{e_p+e_d}<\Delta_2$ if and only if $e_uU_f^B+(e_p+e_d)D_f^B<e_uU_c^H+(e_p+e_d)D_c^H$. In addition, $\frac{e_u}{e_p+e_d}<\Delta_2$ defines a non-empty set since $\Delta_2>0$ in this region, and $r>g_4$ implies that $r>f_2$. Thus, the result follows.

For $R2$, finally, note that when $f_2 < r \le g_4$, $U_f^B \ge U_c^H$ and $D_f^H \ge D_c^B$, and hence, servicization can never improve the environmental impact regardless of the product type.

In R3, under selling, product use impact, and production and disposal impact are same as in $R2$, i.e., use impact is $e_u \frac{M\beta\theta^3}{4k(1+m_c)^2} = e_u U_c^H$ and production and disposal impact is $(e_d+e_p)\frac{4kM\beta(1+m_c)^2}{\theta^3}$. Under servicization product use impact is $e_u \frac{M\beta\theta^3}{4k\left(1+m_f\right)^2} = e_u U_f^H$. Comparison of the use impacts shows that the use impact under servicization is lower if and only if $r<1$. Under servicization, product production and disposal impact is given by $(e_d+e_p)\frac{4kM\beta\left(1+m_f\right)^2}{\theta^3}$. Comparison of the production and disposal impacts shows that production and disposal impact under servicization is lower than under selling if and only if $r>1$.

Let $\Delta_3 = \frac{D_c^H - D_f^H}{U_f^H - U_c^H}$. We now show that in $R3$, for low relative use impact products characterized by $\frac{e_u}{e_p+e_d} < \Delta_3$, the necessary and sufficient condition for servicization to decrease the environmental impact and increase the profit is $r>1$. We know that $r>1$ if and only if $D_c^H > D_f^H$ and $U_c^H < U_f^H$. Therefore $\frac{e_u}{e_p+e_d} < \Delta_3$ if and only if $e_u U_f^H + (e_p+e_d) D_f^H < e_u U_c^H + (e_p+e_d) D_c^H$. In addition, $\frac{e_u}{e_p+e_d} < \Delta_3$ defines a feasible set since $\Delta_3 > 0$ in this region, and the profit is higher under servicization if and only if $r>1$. Thus, the result follows.

Finally we define,

$$\Delta(\alpha,\beta,m_c,m_f) = \begin{cases} \Delta_1 & : \text{in R1} \\ \Delta_2 & : \text{in R2} \\ \Delta_3 & : \text{in R3} \end{cases} \quad \overline{r}(\alpha,\beta) = \begin{cases} g_1 & : \text{in R1} \\ 0 & : \text{in R2} \\ 0 & : \text{in R3} \end{cases} \quad \underline{r}(\alpha,\beta) = \begin{cases} g_2 & : \text{in R1} \\ g_4 & : \text{in R2} \\ 1 & : \text{in R3} \end{cases}.$$

□

Proof of Corollary 1 In the proof of Proposition 4, we showed that $g_2 > g_1$, which proves the result. □

Proof of Proposition 5: $CS_f^{R1} = \sum_{i=L,H}\int_0^{\tau_{i,f}^*}(\theta_i - \frac{t}{\delta})dt - F_i = \frac{M(-1+\alpha)\beta\theta^4}{8c}\left(\frac{\alpha^2(1+\alpha)}{(1+m_c)^2} - \frac{2(\alpha-\beta)\left(\alpha^2+\beta-2\alpha\beta\right)}{(-1+\beta)^2\left(1+m_f\right)^2}\right)$ and $CS_c^{R1} = \sum_{i=L,H}\int_0^{\tau_{i,c}^*}(\theta_i - \frac{t}{\delta})dt - \frac{m_c}{2\delta}\tau_{i,c}^{*2} - p = -\frac{M\alpha^2\left(-1+\alpha^2\right)\beta\theta^4}{8c(1+m_c)^2}$. $CS_f^{R1} > CS_c^{R1}$ if and only if $-\left(\frac{\alpha^2(1+\alpha)}{(1+m_c)^2} - \frac{2(\alpha-\beta)\left(\alpha^2+\beta-2\alpha\beta\right)}{(-1+\beta)^2\left(1+m_f\right)^2}\right) > 0$. Then, $CS_f^{R1} > CS_c^{R1}$ if and only if $r^2 > \frac{(1-\beta)^2\alpha^2(1+\alpha)}{2(\alpha-\beta)(\alpha^2+\beta-2\alpha\beta)} = h^2$, and the result follows. $h>1$ if and only if $(-1+\alpha)\left(-\alpha^2+2\alpha\beta-2\alpha^2\beta-2\beta^2+2\alpha\beta^2+\alpha^2\beta^2\right)>0$. $\alpha<1$ by assumption; hence, if we show that second expression is negative, the result follows. Second derivative of the expression is $2(-1+(-2+\beta)\beta)<0$; hence, it is concave in α. At $\alpha=1$, it is $-1+\beta^2<0$, and at $\alpha=\beta$, it is $\beta^2\left(-1+\beta^2\right)<0$. Therefore, the expression is negative in $R1$.

In R2, the firm has to leave positive informational rent to high end segment under servicization. However, the firm extracts the entire surplus under selling. Hence, the CS under servicization is always higher. In R3, since the firm only serves high-end segment, the CS is zero for both selling and servicization strategies. □

Proof of Proposition 6 This can be shown easily by comparing Proposition 4 and 5. Hence, it is omitted. □

Proof of Proposition 7: The analysis are very similar to Proposition 1 except that we need to account for different product durabilities. Under servicization, if the firm serves only the high end segment, it solves the problem in (7). On the other hand, if it serves both segments, it solves the following:

$$\max_{F_i,\tau_i,\delta_i,i=H,L} \sum_{i=H,L}(F_i - \frac{m_f\tau_i^2}{2\delta_i} - k\delta_i^2)Q_i, \tag{11}$$

$$\begin{aligned} s.t. \qquad & IR_i^{pl}: \qquad \int_0^{\tau_i}(\theta_i - \frac{t}{\delta_i})dt - F_i \ge 0, \quad i=H,L \\ & IC_i^{pl}: \qquad \int_0^{\tau_i}(\theta_i - \frac{t}{\delta_i})dt - F_i \ge \int_0^{\tau_j}(\theta_i - \frac{t}{\delta_j})dt - F_j, \quad i \ne j \text{ and } i,j=H,L. \end{aligned}$$

Similarly, under selling, if the firm serves only the high end segment, it solves the problem in (2). On the other hand, if it serves both segments, it solves the following:

$$\max_{F_i,\delta_i,i=H,L} \sum_{i=H,L}(F_i - k\delta_i^2)Q_i, \quad s.t. \quad U_c(\theta_L) \geq 0 \quad . \tag{12}$$

Finally, comparison of these two strategies will give the optimal strategy and the decisions as stated. □

Proof of Proposition 8: This can be easily shown by computing the average product durabilities using Table 3 and then comparing these average product durabilities. Hence, it is omitted. □

Proof of Proposition 9: For simplicity, we drop the superscript *pl* when we refer to the equilibrium regions. It can be shown that in $R2$ servicization increases use impact if and only if $r^2 > \frac{(\beta-1)^2\beta}{\alpha^3-3\alpha^2\beta+(3\alpha-2)\beta^2+\beta} \triangleq u_{R2}$ and the disposal impact if and only if $r^2 < -\frac{\beta\left(\alpha^3-3\left(\alpha^2-2\right)\beta+(3\alpha-4)\beta^2-4\right)+1}{\beta(\beta-\alpha)^3} \triangleq d_{R2}$. We will prove that $u_{R2} < \overline{f}_2^2 < d_{R2}$. $u_{R2} < \overline{f}_2^2$ if and only if $-(\alpha-1)(\alpha-\beta)^3 > 0$, which is always true for $R2$.

$$d_{R2} - \overline{f}_2^2 = \frac{\nu_1}{\beta(\alpha-\beta)^3\left(\alpha^4 - 4\alpha^3\beta + 3\left(2\alpha^2-1\right)\beta^2 + (3-4\alpha)\beta^3 + \beta\right)} > 0.$$

By some algebra, it can be shown that the denominator is always positive in $R2$. Thus, we can only work with ν_2. Starting with $i = 5$, it can be shown that $\partial^i\nu_1/\partial\alpha^i > 0$ for all $i \in \{1,2,3,4,5\}$. In addition, $\lim_{\beta\to 0}\nu_1(\alpha) = 0$. Thus, $\nu > 0$ in $R2$. Define $\Delta_{R2}^{pl} \triangleq \frac{\beta/\tau_{H,c}-\beta/\tau_{H,f}-(1-\beta)/\tau_{L,f}}{\beta\tau_{H,f}+(1-\beta)\tau_{L,f}-\beta\tau_{H,c}}$. Similarly for $R3$, we can define $\Delta_{R3}^{pl} \triangleq \frac{\beta/\tau_{H,c}-\beta/\tau_{H,f}}{\beta\tau_{H,f}-\beta\tau_{H,c}}$. Finally, define

$$\Delta^{pl}(\alpha,\beta,m_c,m_f) = \begin{cases} \Delta_{R2}^{pl} & : \text{in R2} \\ \Delta_{R3}^{pl} & : \text{in R3} \end{cases} \qquad \underline{r}^{pl} = \begin{cases} \sqrt{d_{R2}} & : \text{in R2} \\ 1 & : \text{in R3} \end{cases} .$$

Then, the result follows. □

Proof of Proposition 10: To find the optimal strategy we need to compare six different strategies: serve both segments by selling (servicization), serve only high end segment by selling (servicization), serve high end segment by selling (servicization) and low end segment by servicization (selling). From Proposition 1, we already know the comparison of the first four strategies. Denote the last two strategies as $(sell, serv.)$ and $(serv., sell)$, respectively. The optimal durability, prices and the use durations for these strategies can be obtained using standard contract design tools similar to Proposition 1 as follows. If the firm uses $(sell, serv.)$ strategy, it solves

$$\max_{\delta,p_H,F_L,\tau_L}(p_H - c\delta^2)Q_H + (F_L - \frac{m_f\tau_L^2}{2\delta} - c\delta^2)Q_L \tag{13}$$
$$s.t. \quad U_c(\theta_H|\theta_H) \geq U_f(\theta_L|\theta_H), \quad U_f(\theta_L|\theta_L) \geq U_c(\theta_H|\theta_L), \quad U_f(\theta_L|\theta_L) \geq 0, \quad U_c(\theta_H|\theta_H) \geq 0.$$

where $U_c(\theta_j|\theta_i)$ and $U_f(\theta_j|\theta_i)$ are utilities of type-i if he takes the contract intended for type-j under selling and servicization models, respectively. Thus,

$$U_c(\theta_j|\theta_i) = \max_{\tau_c}\int_0^{\tau_c}\left(\theta_i - \frac{t}{\delta}\right)dt - \frac{m_c\tau_c^2}{2\delta} - p_j \text{ and } U_f(\theta_j|\theta_i) = \theta_i\tau_j - \frac{\tau_j^2}{2\delta} - F_j$$

Similarly, when the firm uses $(serv, sell)$ strategy, it solves

$$\max_{\delta,p_L,F_H,\tau_H}(p_L - c\delta^2)Q_L + (F_H - \frac{m_f\tau_H^2}{2\delta} - c\delta^2)Q_H \tag{14}$$
$$s.t. \quad U_c(\theta_L|\theta_L) \geq U_f(\theta_H|\theta_L), \quad U_f(\theta_H|\theta_H) \geq U_c(\theta_L|\theta_H), \quad U_f(\theta_H|\theta_H) \geq 0, \quad U_c(\theta_L|\theta_L) \geq 0.$$

Strategy	δ^*	τ^*	π^*
$(Sell, Serv.)$	$-\frac{\theta^2\left(\alpha^2-2\alpha\beta+\beta+(\alpha-\beta)^2 m_c-(\beta-1)\beta m_f\right)}{4(\beta-1)k(m_c+1)\left(m_f+1\right)}$	$\tau_H^*=\frac{\theta\delta^*}{1+m_c},\ \tau_L^*=\frac{\theta(\alpha-\beta)\delta^*}{(1-\beta)\left(1+m_f\right)}$	$kM\delta^{*2}$
$(Serv., Sell)$	$\frac{\theta^2\left(\alpha^2+\beta m_c+\left(\alpha^2-\beta\right)m_f\right)}{4k(1+m_c)\left(1+m_f\right)}$	$\tau_H^*=\frac{\theta\delta^*}{1+m_f},\ \tau_L^*=\frac{\alpha\theta\delta^*}{1+m_c}$	$kM\delta^{*2}$

Table 4 Equilibrium under hybrid strategy.

Table 4 gives the equilibriums. Comparison of all six strategies yields the result, where

$$m_1(\alpha,\beta,m_c)=\begin{cases}-\frac{(\alpha-1)^2\beta+(\alpha-\beta)^2 m_c}{(\beta-1)(\alpha^2-\beta)} & : \text{in R1}\\ \frac{\left(\sqrt{\beta}+1\right)\left(\alpha^2-2\alpha\beta+\beta^{3/2}+\beta-\sqrt{\beta}+(\alpha-\beta)^2 m_c\right)}{(\beta-1)^2\sqrt{\beta}} & : \text{in R2}\end{cases}$$

□

Proof of Proposition 11: The result can be found by comparing the product durabilities in Tables 1 and 4. Hence, omitted. □

Proof of Proposition 12: This can be shown similar to Proposition 4 using the use durations in Table 4. Hence, omitted. In the proposition, $m_3=\max\left(m_c,m_4\right)$, and

$$\beta_1=\min\left(\alpha^4,\frac{-\alpha^3+4\alpha^2-1}{2(2\alpha-1)}-\frac{1}{2}\sqrt{\frac{\alpha^6-8\alpha^5+16\alpha^4-14\alpha^3+8\alpha^2-4\alpha+1}{(2\alpha-1)^2}}\right),\quad \Delta_h=\frac{D_c^B-D_{(sell,serv.)}}{U_{(sell,serv.)}-U_c^B}.$$

In the above expressions $D_{(sell,serv.)}$ ($U_{(sell,serv.)}$) denotes total production and disposal impacts (use impact) under the hybrid strategy, and D_r^B (U_c^B) are given in the proof of Proposition 4. m_4 can be found as the larger root of $U_{(sell,serv.)}-U_c^B$. $U_{(sell,serv.)}-U_c^B$ can be shown to have to two roots with respect to m_f. Finally, m_2 can be found as the larger root of $D_{(sell,serv.)}-D_c^B$. $D_{(sell,serv.)}-D_c^B$ can be shown to have to two roots with respect to m_f. Due to page count limitations, we do not state these roots in the paper explicitly; however, the details are available from the authors. □

Proof of Proposition 13: In R1, $SS_{f,B}=-\frac{M\left(-\alpha^2-\beta+2\alpha\beta\right)\left(\alpha^2+\beta+2(1-2\alpha)\alpha\beta+4(-1+\alpha)\beta^2\right)\theta^4}{16k(-1+\beta)^2\left(1+m_f\right)^2}$ and $SS_{c,B}=\frac{M\alpha^2\left(\alpha^2(1-2\beta)+2\beta\right)\theta^4}{16k(1+m_c)^2}$. By rearranging the terms, $SS_{f,B}>SS_{c,B}$ if and only if $r^2>\frac{\alpha^2(-1+\beta)^2\left(-2\beta+\alpha^2(-1+2\beta)\right)}{(\alpha^2+\beta-2\alpha\beta)(-2\alpha\beta(1+2\beta)+\alpha^2(-1+4\beta)+\beta(-1+4\beta))}\triangleq k_1^2$. We need to show that $k_1>f_1$. This is true if and only if $\frac{\alpha^2(-1+\beta)^2\left(-2\beta+\alpha^2(-1+2\beta)\right)}{(\alpha^2+\beta-2\alpha\beta)(-2\alpha\beta(1+2\beta)+\alpha^2(-1+4\beta)+\beta(-1+4\beta))}>\frac{\alpha^4(-1+\beta)^2}{(\alpha^2+\beta-2\alpha\beta)^2}$. This inequality can be written as $-\frac{2(-1+\alpha)^2\alpha^2(-1+\beta)^2\beta\left(\alpha^2+\beta\right)}{(\alpha^2+\beta-2\alpha\beta)^2(-2\alpha\beta(1+2\beta)+\alpha^2(-1+4\beta)+\beta(-1+4\beta))}>0$. Note that numerator is always positive and $(\alpha^2+\beta-2\alpha\beta)^2>0$. Hence, we need to show that $e_1\triangleq-(-2\alpha\beta(1+2\beta)+\alpha^2(-1+4\beta)+\beta(-1+4\beta))>0$. $\frac{\partial^2 e_1}{\partial\beta^2}=8(-1+\alpha)<0$, and hence, e_1 is concave in β. Then it is sufficient to show that e_1 is positive at $\beta=0$ and $\beta=\alpha$. $e_1(\beta=0)=\alpha^2$ and $e_1(\beta=\alpha)=\alpha(1-\alpha)$. This proves that when servicization is more profitable than selling strategy in R1, $SS_{f,B}>SS_{c,B}$ if and only if $r>k_1$. To complete the proof for region $R1$, we need to find when $k_1>1$ is true. Observe that this is true if and only if $l=-1-2\alpha+5\alpha^2+(4-2\alpha(2+\alpha))\beta>0$. When $\beta<\frac{1}{2}$, l has two roots $\alpha_1^l=\frac{-1-2\beta-\sqrt{6}\sqrt{1-3\beta+2\beta^2}}{-5+2\beta}$ and $\alpha_2^l=\frac{-1-2\beta+\sqrt{6}\sqrt{1-3\beta+2\beta^2}}{-5+2\beta}$. Furthermore, $\alpha_1^l>\alpha_2^l$ and $\alpha_2^l<\beta$. Since, l is convex in this region, $l>0$ if and only if $\alpha>\min\{\alpha_1^l,\sqrt[4]{\beta}\}$. $\frac{\partial\alpha_l^1}{\partial\beta}<0$ for $\beta\in(0,0.5)$. $\alpha_l^1(\beta=0)\approx 0.69$ and $\alpha_l^1(\beta=1)=0.5$. Therefore, there exist a $\beta_c\in(0,0.5)$ such that $\alpha_1^l>\sqrt[4]{\beta}$ if and if $0<\beta<\beta_c$. When $\beta\geq\frac{1}{2}$, l does not have any roots. Hence it is either always positive or always negative. It is easy to see that it is always positive. Then, define

$$\sigma(\beta)=\begin{cases}\sqrt[4]{\beta} & :\beta\geq\beta_c\\ \alpha_1^l & :\beta<\beta_c\end{cases}$$

In R2, $SS_{c,H} = \frac{M\beta\theta^4}{16k\left(1+m_f\right)^2}$. By rearranging the terms we can show that $SS_{f,B} > SS_{c,H}$ if and only if $r > \sqrt{-\frac{(-1+\beta)^2\beta}{(-\alpha^2-\beta+2\alpha\beta)(\alpha^2+\beta+2\alpha\beta-4\alpha^2\beta-4\beta^2+4\alpha\beta^2)}} \triangleq k_2$. $f_2 > k_2$ if and only if $\frac{(1-\beta)^2\beta}{(\alpha^2+\beta-2\alpha\beta)^2} > -\frac{(-1+\beta)^2\beta}{(-\alpha^2-\beta+2\alpha\beta)(\alpha^2+\beta+2\alpha\beta-4\alpha^2\beta-4\beta^2+4\alpha\beta^2)}$. The inequality can be written as $(\alpha^2+\beta-2\alpha\beta)(-1-\alpha^2-\beta-2\alpha\beta+4\alpha^2\beta+4\beta^2-4\alpha\beta^2)<0$. First expression in the equality is convex in α and takes its minimum value at $\alpha=\beta$ which is $\beta(1-\beta)>0$. Second expression is convex in β, and hence, it is sufficient to show that it is negative at $\beta=0$ and $\beta=\alpha$. These can be shown by simple algebra.

In R3, since the SS is equivalent to firm's profit under both selling and servicization. The proof is same as the comparison of the profits in the proof of Proposition 2. □

Proof of Lemma 2: These can be shown easily by comparing the product durabilities and consumer segments' use durations in Proposition 1 in this paper and Proposition 17 in Orsdemir et al. (2017). □

Proof of Proposition 14 Define $U_i^{pl} = \beta M\tau_{i,H} + (1-\beta)M\tau_{i,L}$ and $D_i^{pl} = \beta M/\tau_{i,H} + (1-\beta)M/\tau_{i,L}$ where $\tau_{i,j}$'s are given in Table 3. In addition, $\Delta_{R1}^{pl} = (D_f^{pl} - D_c^{pl})/(U_c^{pl} - U_f^{pl})$. Finally, it can be shown that $\pi_f > \pi_c$ if and only if $r > \frac{(\beta-1)^2\left(\alpha^4-2\alpha^2\beta+\beta\right)}{\alpha^4-4\alpha^3\beta+3(2\alpha^2-1)\beta^2+(3-4\alpha)\beta^3+\beta}$. Then, the proposition follows. □