The Potential of Servicizing as a Green Business Model

Vishal V. Agrawal
McDonough School of Business, Georgetown University, Washington, DC 20057, vishal.agrawal@georgetown.edu

Ioannis Bellos
School of Business, George Mason University, Fairfax, VA 22030, ibellos@gmu.edu

It has been argued that servicizing business models, under which a firm sells the use of a product rather than the product itself, are environmentally beneficial. The main arguments are: First, under servicizing the firm charges customers based on the product usage. Second, the quantity of products required to meet customer needs may be smaller because the firm may be able to pool customer needs. Third, the firm may have an incentive to offer products with higher efficiency. Motivated by these arguments, we investigate the economic and environmental potential of servicizing business models. We endogenize the firm's choice between a pure sales, a pure servicizing, and a hybrid model with both sales and servicizing options, the pricing decisions and, the resulting customer usage. We consider two extremes of pooling efficacy, viz., no versus strong pooling. We find that under no pooling servicizing leads to higher environmental impact due to production but lower environmental impact due to use. In contrast, under strong pooling, when a hybrid business model is more profitable, it is also environmentally superior. However, a pure servicizing model is environmentally inferior for high production costs as it leads to a larger production quantity even under strong pooling. We also examine the product efficiency choice and find that the firm offers higher efficiency products only under servicizing models with strong pooling.

Key words: sustainable operations; servicizing; environment; product design; business models
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1. Introduction

An emerging paradigm among manufacturers in various industries involves the implementation of innovative business models that sell the functionality or use of a product instead of the product itself. For example, rather than only selling printers, Xerox also offers "document management" services under which it charges customers for each page they print (Fischer et al. 2012, Xerox 2013a). Similarly, through its SmartCloud program, IBM offers computing and storage services and charges customers for the use of the servers (IBM 2013a). The transition to such business models, under which firms sell the use of the products, has been termed as *servicizing* (cf., Toffel 2008). Servicizing business models have received growing attention from several environmental groups and agencies because of their potential environmental benefits (White et al. 1999, Rothenberg 2007, U.S. Environmental Protection Agency 2009, Fischer et al. 2012).

The main arguments in support of the environmental superiority of servicizing are: First, under servicizing, the firm typically employs pay-per-use pricing, which directly links the price charged to the customers' product usage (e.g., the number of pages printed, GB used, or the time the product is used). Therefore, from the customers' perspective, such business models transform the fixed cost associated with the ownership of the product to a variable cost associated with the use of the product. This may incentivize customers to curtail their usage, lowering the environmental impact due to product use. Second, under some servicizing models, instead of providing each customer with a dedicated product, the firm may maintain a pool of products from which customers' needs are met. Such pooling may enable the firm to meet customer needs with fewer units, reducing the environmental impact due to production. Third, as the firm is paid based on customers' usage, it may have a greater incentive to offer products with higher efficiency in order to reduce the operating costs associated with the use of the products. Higher efficiency products may lower the environmental impact during use as they require less energy and resources.

Despite the popularity of these arguments, the environmental superiority of servicizing is not clear (cf., U.S. Environmental Protection Agency 2009, p. 19). The reason is that the above arguments do not account for the full scope of how the firm's and a customer's decisions depend on the structural characteristics of servicizing business models. For example, under servicizing, the pricing is based only on the product usage, and for that reason, the firm may be able to reach customers who do not buy the product under a conventional sales model. This may lead to a larger number of customers adopting and using a product, making servicizing environmentally inferior. In addition, while pooling may reduce the production volume, it may also enable the firm to charge a lower price and further increase the product adoption and usage. Moreover, if the firm offers a more efficient product, then customers may increase their product usage due to the lower operating costs. This phenomenon is commonly known as the *rebound effect* (see Greening et al. 2000 for an overview). Such an increase in the customer usage would lead to higher total environmental impact due to use. Even if servicizing itself is environmentally beneficial, instead of only offering a servicizing option, the firm may prefer to offer a "hybrid" business model that includes both a sales and a servicizing option. This may attenuate the potential environmental benefits of servicizing. Therefore, it is not clear whether and when servicizing business models are environmentally superior.

In this paper, we analytically investigate when and why servicizing is both more profitable and environmentally superior to a conventional sales model. We develop an analytical model that captures the differences in the structural characteristics of servicizing business models commonly found in practice. In particular, we allow the firm to choose between offering a conventional sales model and two different types of servicizing models: i) a hybrid model with both a sales and a servicizing option or ii) a pure servicizing model with only a servicizing option. Under a servicizing option, the firm employs pay-per-use pricing and may be able to meet customer needs with fewer products. We explicitly account for the firm's ability to meet customers' needs with fewer products by varying the efficacy of pooling from strong to none, with the latter implying that the firm provides each customer with a dedicated product. We also account for heterogeneity in customers' usage needs and endogenize their usage decisions. This allows us to identify how customers' usage changes across the business models due to the differences in pricing and the extent to which the firm can meet customer needs with fewer products. Moreover, we also endogenize the firm's choice of product efficiency and examine whether the firm prefers to offer a product with higher efficiency under a servicizing model.

Our results offer several key insights for firms and environmental groups regarding when and why servicizing business models are both more profitable and environmentally beneficial. First, when there is no pooling, the firm prefers to offer servicizing only through a hybrid model. In this case, we find that the hybrid business model is environmentally superior only for products such as printers and aircraft engines that have the majority of their environmental impact in the use phase. Therefore, our results suggest that business models like Xerox's document management services or Volvo Aero's power-by-the-hour program for engines are environmentally superior.

Second, we find that under strong pooling, the firm prefers to offer a hybrid business model when the production cost is low and a pure servicizing business model when the production cost is high. One would expect servicizing models with stronger pooling to result in a smaller production quantity, and thus lower environmental impact due to production. Accordingly, we do find that when the firm prefers to offer a hybrid business model under strong pooling, it is also environmentally superior. However, under strong pooling, a pure servicizing business model is actually environmentally inferior for high production costs because it leads to a larger quantity of products than pure sales. Therefore, our results suggest that cloud and storage services, which are characterized by strong pooling, are environmentally superior for low-cost servers as the firm prefers to offer a hybrid model. On the other hand, they are environmentally inferior for high-cost servers as the firm prefers to offer a pure servicizing model, as in the case of IBM's SmartCloud program. Hence, our results offer important insights for managers and policy makers regarding how the economic and environmental performance of servicizing depends on the structure of the business model, specifically, whether it is offered through a hybrid or a pure servicizing model.

Third, despite the fact that the firm's revenue is linked to the customers' usage, we show that the firm actually offers lower efficiency products under a servicizing business model when there is no pooling. However, when pooling is strong, the firm does offer more efficient products. This highlights the importance of accounting for operational characteristics such as the pooling efficacy, to assess the environmental performance of servicizing. We also identify a novel mechanism for the environmental superiority of servicizing by showing that it moderates (or even eliminates) the rebound effect.

2. Literature Review

Our work contributes to two different streams of literature in sustainable operations, viz., research on environmentally sustainable business models (cf., Girotra and Netessine 2013 for an overview) and research on green product design (cf., Agrawal and Toktay 2009 for an overview).

An emerging stream of literature in operations management analyzes the environmental performance of business models that decouple customer value from product ownership. For example, Agrawal et al. (2012) investigate when product leasing is environmentally superior to sales. In this paper, we focus on servicizing, which differs from leasing in two important aspects: i) the payment is directly linked to product usage and ii) the firm may not have to dedicate one product to each customer. Closer in spirit to our work are papers that analyze the intricacies of specific servicizing business models. Motivated by chemical management services used in the automotive industry, Corbett and DeCroix (2001) and Corbett et al. (2005) examine shared-savings contracts for materials such as chemical solvents, and analyze whether such contracts lead to a decrease in consumption of indirect materials. Bellos et al. (2013) study the economic and environmental implications of an auto manufacturer's decision to offer car sharing. Avci et al. (2015) analyze the implementation of business models posed to eliminate range anxiety for electric vehicles by providing battery-switching stations and by charging customers only for the use of the batteries. In a similar context, Lim et al. (2015) study whether leasing batteries and/or offering different charging options can increase adoption of electric vehicles, in the presence of range and resale anxiety.

These papers consider the firm's choice of business model. However, they do not account for product design decisions. Moreover, most of them do not consider the case where the firm may offer a hybrid business model, which provides customers with both a sales and a servicizing option. In this paper, we explicitly investigate how the firm's product efficiency choice influences the environmental performance of servicizing and we also consider the firm's optimal choice between a pure sales, a pure servicizing, and a hybrid business model.

Another stream of literature in sustainable operations examines the environmental implications of a firm's product design and development decisions. Several papers focus on design decisions such as product modularity (Agrawal and Ülkü 2013) or replacement of hazardous substances (Kraft et al. 2013). Other studies also examine the effect of environmental legislation on product design, such as efficiency and remanufacturability (Subramanian et al. 2009), and development time and expenditure (Plambeck and Wang 2009). However, these papers focus only on conventional sales business models. Recent papers have also studied product design decisions under performance-based contracting, a type of servicizing business model under which payment to the firm is linked to the uptime of the product. In such a setting, Kim et al. (2011) and Guajardo et al. (2012) investigate a manufacturer's choice of product reliability. In a similar vein, Chan et al. (2014) study the effect of pay-per-service versus fixed-fee maintenance plans on the reliability of medical equipment. However, these papers do not analyze the environmental implications or explicitly account for the customer usage decisions. We contribute to this stream of literature by investigating how the firm's product efficiency choice differs across different business models when customers' usage decisions are endogenized. This allows us to capture how a product design choice such as efficiency, depends on the choice and structure of the business model, and on operational characteristics such as the efficacy of pooling.

Overall, in the context of servicizing, this is the first paper, to the best of our knowledge, to analyze the joint effect of product design and business model choices on the firm's economic and environmental performance.

3. The Model

We formulate a sequential, firm-customer game, where a profit-maximizing monopolist makes its decisions, followed by the customers. The sequence of events is the following: The firm determines the product efficiency and then chooses between offering a pure sales or a servicizing business model. Subsequently, it sets the sales and/or pay-per-use price, and the customers make their usage decisions.

The firm chooses the product efficiency denoted by $e \in [0,1]$. A higher value of e implies a more efficient product. Specifically, $e = 0$ represents the baseline efficiency whereas $e = 1$ represents the maximum feasible product efficiency. The firm's choice of product efficiency influences the production and operating costs. We denote the cost of manufacturing a product by $c(e)$. As manufacturing a more efficient product may require higher quality materials, we assume that $c(e)$ is increasing in product efficiency. The operating cost per unit of usage is denoted by $k(e)$. We assume that $k(e)$ decreases in the product efficiency because a more efficient product requires less energy and fewer resources during its use (i.e., it offers the same level of use at a lower cost).

The firm next decides which business model to offer. Specifically, it chooses among the following business models: i) a pure sales model, under which it offers only a sales option, ii) a pure servicizing business model, under which it offers only a servicizing option, and iii) a hybrid business model, under which it offers both a sales and a servicizing option. For brevity, we refer to the pure servicizing and hybrid business models collectively as servicizing business models. We use the superscript $i \in \{p, h\}$ to indicate a pure (i.e., $i = p$) or a hybrid (i.e., $i = h$) business model and the subscript $j \in \{sa, se\}$ to denote the sales (i.e., $j = sa$) or the servicizing (i.e., $j = se$) option. Given the business model, the firm makes its pricing decisions. Under the sales option, the firm sells the product to the customers by charging a fixed sales price, f^i_{sa}, whereas under the servicizing option, the firm sells the usage of the product by charging a per unit of usage (e.g., per-page printed, GB used, or time the product is used) price, f^i_{se}.[1]

Observing the product efficiency and the prices under a given business model, the customers then decide through which option to satisfy their needs, and also determine their product usage q^i_j. Customers are heterogeneous in terms of their usage need θ. We assume θ is uniformly distributed between zero and one. Without loss of generality, we normalize the size of the customer population to one. The gross utility a customer of type θ derives from a product usage q^i_j is given by $V_\theta\left(q^i_j\right) \doteq \frac{1}{b}\left(\theta q^i_j - \frac{(q^i_j)^2}{2}\right)$, which is concave increasing in q^i_j. Therefore, a customer derives greater utility from higher usage but with decreasing returns and never chooses a $q^i_j > \theta$. The parameter b can be interpreted as the change in usage per unit change in the operating cost and/or pay-per-use price (cf. Lambrecht et al. 2007), which can also be observed in Lemma 1 below.

We assume that customers are always responsible for the operating cost $k(e)$ incurred per unit of usage. Our results remain unchanged if we relax this assumption to account for the case where under the servicizing option the firm bears the operating cost. The reason is that the firm simply transfers the cost to the customers. In §5.5, we also discuss how our results are influenced in the case where the operating cost is lower if incurred by the firm. The firm charges a usage-independent price, f^i_{sa}, under the sales option, and a pay-per-use price, f^i_{se}, under the servicizing option. Therefore, the net utility of customer θ is given by $U^i_{sa}\left(q^i_{sa};\theta, f^i_{sa}, e\right) \doteq V_\theta\left(q^i_{sa}\right) - k\left(e\right) q^i_{sa} - f^i_{sa}$ and $U^i_{se}\left(q^i_{se};\theta, f^i_{se}, e\right) \doteq V_\theta(q^i_{se}) - \left(k\left(e\right) + f^i_{se}\right)q^i_{se}$ under the sales and servicizing option, respectively.[2]

3.1 Customers' problem

For any option $j \in \{sa, se\}$ under a given business model $i \in \{p, h\}$, the customers maximize their net utility by choosing their usage, q^i_j. The utility-maximization problem of a customer θ is given by $\max_{q^i_j \geq 0} U^i_j\left(q^i_j;\theta, f^i_j, e\right)$, where $U^i_j\left(q^i_j;\theta, f^i_j, e\right)$ is strictly concave in q^i_j and increasing in θ. Let $q^{i^*}_j\left(\theta; f^i_j, e\right)$ denote the optimal usage obtained by solving customer θ's problem. The next lemma compares the optimal usage of a customer under the sales and the servicizing option.

Lemma 1. *The individual usage of an adopting customer θ is lower under the servicizing option than under the sales option. Specifically,* $q^{i^*}_{se}\left(\theta; f^i_{se}, e\right) \doteq \theta - b\left(f^i_{se} + k\left(e\right)\right) < q^{l^*}_{sa}\left(\theta; f^l_{sa}, e\right) \doteq \theta - bk\left(e\right)$, *where* $i, l \in \{p, h\}$.

[1] We assume that under servicizing the firm does not incur any transaction cost for monitoring the customers' usage. Such a cost lowers the profitability of servicizing, but may improve its relative environmental performance as the firm charges a higher pay-per-use price to recoup it.

[2] The customer utility is quadratic in q^i_j, leading to an optimal usage that is linear in the pay-per-use price. In §5.4, we also consider utility functions that result in nonlinear optimal usage.

The individual usage of a customer is lower under the servicizing option due to the pay-per-use pricing. Under the sales option, the usage-independent price acts as a sunk cost, and an additional unit of usage does not increase the price paid by the customer. However, under the servicizing option, the customer pays the firm for each additional unit of usage, and thus, all else being equal, chooses a lower usage. This illustrates a key driver behind one of the main arguments for the environmental superiority of servicizing, viz., that pay-per-use pricing incentivizes customers to curtail their consumption. However, the above result does not characterize how pay-per-use pricing influences the number of customers that choose an option, which as we discuss later, may lead to higher aggregate usage.

Under a given business model, the customers decide which option maximizes their net utility. Under a pure sales model, a customer can choose to purchase the product or remain inactive. Similarly, under a pure servicizing model, a customer can choose to participate in servicizing or remain inactive. Let the marginal customer who is indifferent between participating in a pure business model and being inactive be denoted by $\Theta_j^p = \left\{\theta : U_j^p\left(q_j^{p^*};\theta, f_j^p, e\right) = 0\right\}$ for $j \in \{sa, se\}$.

Under a hybrid business model, a customer can choose to purchase the product through the sales option, participate in the servicizing option, or remain inactive. Let the marginal customer indifferent between the sales and the servicizing option be denoted by $\Theta_1^h = \left\{\theta : U_{sa}^h\left(q_{sa}^{h^*};\theta, f_{sa}^h, e\right) = U_{se}^h\left(q_{se}^{h^*};\theta, f_{se}^h, e\right)\right\}$ and the marginal customer indifferent between participating in the servicizing option and being inactive be denoted by $\Theta_2^h = \left\{\theta : U_{se}^h\left(q_{se}^{h^*};\theta, f_{se}^h, e\right) = 0\right\}$. It is straightforward to show that customers in $\theta \in [\Theta_1^h, 1]$ choose sales, customers in $\theta \in [\Theta_2^h, \Theta_1^h)$ choose servicizing and, the rest remain inactive. That is, the customers who have higher usage needs purchase the product, and those with lower usage needs participate in servicizing. The reason is that under the sales option, the price f_{sa}^i, that customers pay is independent of their usage. However, under the servicizing option a customer θ effectively pays $f_{se}^i q_{se}^{i^*}(\theta)$, which is higher for customers with higher usage needs θ.

3.2 Firm's problem

We now formulate the firm's problem. Let $n_j^p\left(f_j^p, e\right)$ denote the number of customers who adopt a pure business model (i.e., the customers who choose to purchase the product or its use). Let $Q_j^p\left(f_j^p, e\right)$ denote the quantity of products required to meet the customer needs. For the hybrid model, let the number of people who choose an option $j \in \{sa, se\}$ be denoted by $n_j^h(f_{sa}^h, f_{se}^h, e)$ and the quantity of products required to meet their needs be denoted by $Q_j^h(f_{sa}^h, f_{se}^h, e)$. Under a servicizing business model, the firm may be able to pool the needs of customers who participate in the servicizing option. Therefore, the quantity of products required to meet the needs of these customers may be lower than the adoption, i.e., $Q_{se}^p(f_{se}^p, e) \leq n_{se}^p(f_{se}^p, e)$ and $Q_{se}^h(f_{sa}^h, f_{se}^h, e) \leq n_{se}^h(f_{sa}^h, f_{se}^h, e)$.

Under the sales option, as the firm provides each customer with a dedicated product, the quantity of products is equal to the adoption, i.e., $Q^p_{sa}(f^p_{sa},e)=n^p_{sa}(f^p_{sa},e)$ and $Q^h_{sa}(f^h_{sa},f^h_{se},e)=n^h_{sa}(f^h_{sa},f^h_{se},e)$.

In addition, we define the aggregate usage under a given option as the amount of product usage aggregated over all adopting customers. Under a pure business model, the aggregate usage is given by $\Omega^p_j(f^p_j,e)=\int_{\Theta^p_j}^1 q^{p^*}_j(\theta;f^p_j,e)d\theta$. Similarly, under the hybrid business model, the aggregate usage for the sales and the servicizing option is given by $\Omega^h_{sa}(f^h_{sa},f^h_{se},e)=\int_{\Theta^h_1}^1 q^{h^*}_{sa}(\theta;f^h_{sa},e)d\theta$ and $\Omega^h_{se}(f^h_{sa},f^h_{se},e)=\int_{\Theta^h_2}^{\Theta^h_1} q^{h^*}_{se}(\theta;f^h_{se},e)d\theta$, respectively.

Under a pure sales model, the firm charges a usage-independent price, f^p_{sa}, for every product sold. The firm's pricing problem is then given by

$$\max_{f^p_{sa}} \Pi^p_{sa}(f^p_{sa};e)\doteq\big(f^p_{sa}-c(e)\big)n^p_{sa}(f^p_{sa};e).$$

Before we formulate the firm's problem for a servicizing business model, we explain how we model the firm's ability to pool customers' needs by maintaining a pool of products for those who choose servicizing. The required quantity of products depends on the efficacy of pooling, which may be influenced by exogenous product or industry related factors. For example, compared to IBM's SmartCloud program, in which the firm can route customer requests at any available server, a model such as Xerox's document management services may be characterized by a weaker pooling effect because certain customers may still require a minimum number of on-site printers. We capture the strength of the pooling effect with the parameter γ. A larger value of γ indicates stronger pooling, implying that, all else being equal, the firm can satisfy the customers' needs by producing a smaller quantity of products (i.e., $Q^i_{se}(\cdot)$ is decreasing in γ). For servicizing business models, (i.e., when $j=se$) hereafter we also include the subscript γ to indicate different degrees of pooling (e.g., $Q^i_{se\gamma}(\cdot)$).

In general, the quantity of products Q^i_{se} required to meet the needs of the customers who choose servicizing depends on the aggregate usage $\Omega^i_{se}(\cdot)$, the strength of the pooling effect γ, and the maximum usage $\bar{q}$ that a product can offer. We normalize $\bar{q}$ to one. Therefore, if pooling is perfect (i.e., if customers' requests do not overlap), then the quantity of products required to meet customer demand under servicizing is given by $Q^i_{se}(\cdot)=\Omega^i_{se}(\cdot)/\bar{q}=\Omega^i_{se}(\cdot)/1$, which under the customers' optimal usage decisions (see Lemma 1), reduces to $Q^i_{se}(\cdot)=\big(n^i_{se}(\cdot)\big)^2/2$. This represents the best case scenario where the firm can achieve maximum pooling. The efficacy of pooling may diminish to the point where the firm provides each customer with a dedicated product, in which case $Q^i_{se}(\cdot)=n^i_{se}(\cdot)$.

To capture the intermediate range between these two extremes of pooling efficacy, one can model the quantity of products required to meet customer needs under servicizing as $Q^i_{se\gamma}(\cdot)\doteq$

$\left(n^i_{se\gamma}(\cdot)\right)^{\gamma}/\gamma$, where the parameter $\gamma \in [1,2]$ represents the strength of the pooling effect. This specification accounts for several important aspects of pooling: First, as the number of adopting customers increases, the firm requires a larger quantity of products (i.e., $Q_{se\gamma}(\cdot)$ is increasing in $n_{se\gamma}$). Second, the quantity of products required is decreasing in the strength of the pooling effect (i.e., $Q_{se\gamma}(\cdot)$ is decreasing in γ). Third, it captures the two extremes of pooling as at $\gamma = 1$, we have the no pooling case (i.e., $Q^i_{se1}(\cdot) = n^i_{se1}(\cdot)$), and at $\gamma = 2$, we have the maximum pooling case (i.e., $Q^i_{se2}(\cdot) = \left(n^i_{se2}(\cdot)\right)^2/2$). The above specification implicitly assumes that the quantity of required products is convex in the adoption (i.e., the efficacy of pooling decreases in the adoption). In §5.2, we show that an alternative queueing-based model of pooling also provides a specification that is convex in the adoption. In §5.3, we examine the robustness of our results to this assumption by extending our analysis to consider an alternative model of pooling with economies of scale, where the quantity of products required is concave in the adoption.

For analytical tractability, in our main analysis we focus on the two extreme cases described by $\gamma \in \{1,2\}$, and we refer to the $\gamma = 1$ case as *no pooling* and the $\gamma = 2$ case as *strong pooling*. We discuss our results for a general $\gamma \in (1,2)$ in §5.1.

Under a pure servicizing model, the firm charges a pay-per-use price $f^p_{se\gamma}$, which along with the aggregate usage determines its overall revenue. The firm's pricing problem under this business model is given by

$$\max_{f^p_{se\gamma}} \Pi^p_{se\gamma}(f^p_{se\gamma}; e) \doteq f^p_{se\gamma}\Omega^p_{se\gamma}(f^p_{se\gamma}; e) - c(e)Q^p_{se\gamma}(f^p_{se\gamma}; e).$$

Under a hybrid business model, the firm charges a usage-independent price $f^h_{sa\gamma}$ for the sales option and a pay-per-use price $f^h_{se\gamma}$ for the servicizing option. Therefore, in this case, the firm's pricing problem can be written as

$$\begin{aligned}\max_{f^h_{sa\gamma}, f^h_{se\gamma}} \; \Pi^h_{\gamma}(f^h_{sa\gamma}, f^h_{se\gamma}; e) &= \Pi^h_{sa\gamma}(f^h_{sa\gamma}, f^h_{se\gamma}; e) + \Pi^h_{se\gamma}(f^h_{sa\gamma}, f^h_{se\gamma}; e) \\ &= \left(f^h_{sa\gamma} - c(e)\right)Q^h_{sa\gamma}(f^h_{sa\gamma}, f^h_{se\gamma}; e) + f^h_{se\gamma}\Omega^h_{se\gamma}(f^h_{sa\gamma}, f^h_{se\gamma}, e) - c(e)Q^h_{se\gamma}(f^h_{sa\gamma}, f^h_{se\gamma}; e).\end{aligned}$$

Let $f^{i^*}_{j\gamma}(e)$ denote the profit-maximizing price under a given business model and efficiency, and define $\widetilde{\Pi}^p_{j\gamma}(e) \doteq \Pi(f^{p^*}_{j\gamma}; e)$ and $\widetilde{\Pi}^h_{\gamma}(e) \doteq \Pi^h_{\gamma}(f^{h^*}_{sa\gamma}, f^{h^*}_{se\gamma}; e)$. The firm's problem of choosing the optimal business model is $\widetilde{\Pi}^*_{\gamma}(e) \doteq \max\left\{\widetilde{\Pi}^p_{sa}(e), \widetilde{\Pi}^p_{se\gamma}(e), \widetilde{\Pi}^h_{\gamma}(e)\right\}$. Finally, the firm's problem of choosing efficiency is given by $\max_{0 \le e \le 1} \widetilde{\Pi}^*_{\gamma}(e)$.

3.3 Environmental impact

In order to measure the total environmental impact of a business model, we adopt a product life cycle perspective, and consider two different phases of the product life cycle, viz., production and use. Let η_m denote the environmental impact due to the production of a unit. The total environmental impact due to production depends on η_m and the quantity of products. Let η_u denote the environmental impact per unit of usage.[3] The total environmental impact due to use depends on η_u and the aggregate usage. The total environmental impact is given by $E_j^p\left(f_j^p, e\right) = \eta_m Q_j^p\left(f_j^p, e\right) + \eta_u \Omega_j^p\left(f_j^p, e\right)$ for a pure business model, where $j \in \{sa, se\}$, and by $E^h\left(f_{sa}^h, f_{se}^h, e\right) = \eta_m\left(Q_{sa}^h\left(f_{sa}^h, f_{se}^h, e\right) + Q_{se}^h\left(f_{sa}^h, f_{se}^h, e\right)\right) + \eta_u\left(\Omega_{sa}^h\left(f_{sa}^h, f_{se}^h, e\right) + \Omega_{se}^h\left(f_{sa}^h, f_{se}^h, e\right)\right)$ for a hybrid model.

4. Analysis and Results

We consider subgame perfect equilibria and solve our analytical model using backward induction. In order to rule out uninteresting cases where the benchmark pure sales model is not profitable, we assume throughout our analysis that the production cost is not prohibitively high (i.e., $c(e) < \frac{\left(1-k(e)\right)^2}{2}$ holds for all $e \in [0,1]$; see Appendix §A1).

4.1 Pricing Decisions and Optimal Business Model Choice.

In this section, we solve for the firm's pricing decisions and the optimal choice of business model for a given product efficiency. This allows us to identify when a servicizing business model is more profitable, and compare its environmental performance to our benchmark of pure sales. We begin by focusing on the case of no pooling (i.e., $\gamma = 1$).

PROPOSITION 1. *Under no pooling: If* $c(e) < C_1\left(k(e)\right)$*, then the firm offers the hybrid business model, which leads to higher adoption and quantity of products, but lower aggregate usage, than under pure sales. Otherwise, the firm offers pure sales.*

Under a hybrid business model, the firm offers both sales and servicizing options, which allows for better price discrimination by more effectively segmenting the customers. In particular, customers with higher usage needs choose the sales option and customers with lower usage needs choose the servicizing option. This makes the hybrid business model more attractive than a pure business model, which provides only one option. However, the firm offers a hybrid business model only if the production cost is sufficiently low. This is because the adoption is higher under the hybrid business model due to pay-per-use pricing, leading to a higher total production cost. When the unit production cost is sufficiently high, the increase in the total production cost outweighs the benefit from better price discrimination, making the hybrid business model less profitable.

Note that a hybrid business model leads to higher product adoption, which results in a larger quantity of products. A higher adoption also implies that there are customers with low usage needs

[3] Our analysis can easily include the environmental impact during disposal by considering η_m to also include the environmental impact due to the eventual disposal of the product. Additionally, both η_m and η_u may depend on the product efficiency. We discuss this case in §4.2.

who are inactive under a pure sales model, but become active under a hybrid model, and therefore, increase their individual usage. However, the aggregate usage is still lower under a hybrid business model. The reason is that as the firm offers both sales and servicizing options, some customers with high usage needs who purchase a product under a pure sales model now switch to the servicizing option. In this case, the individual usage of the switching customers decreases (see Lemma 1). Overall, this decrease dominates the increase in the individual usage of customers who become active under a hybrid business model, leading to lower aggregate usage.

Based on the above result, we now summarize the environmental performance of servicizing business models when they are more profitable under no pooling.

COROLLARY 1. *Under no pooling: A servicizing business model is environmentally superior only for products that have the majority of their impact in the use phase, i.e.,* $\omega \doteq \frac{\eta_m}{\eta_m+\eta_u} \leq \omega_1$.

Corollary 1 shows that even with no pooling, a servicizing business model can be environmentally superior for products such as printers and aircraft engines, which have most of their environmental impact in the use phase (cf., Xerox 2010, Lopes 2010). This implies that, despite the limited pooling ability, business models such as Xerox's document management services or Volvo Aero's power-by-the-hour program (Fischer et al. 2012) can be environmentally superior. However, a servicizing business model is environmentally inferior to sales for products such as heavy machinery or tires that have the majority of their impact in the production phase. Hence, in contrast to the proposed arguments in practice that pay-per-use pricing may result in servicizing business models being environmentally superior, we find that it may actually render them environmentally inferior.

The above result is similar in spirit to some findings of previous research on certain business models where customers do not own the product and the firm dedicates a product to each customer. However, the underlying mechanism differs in our context. In particular, Agrawal et al. (2012) show that leasing may lead to higher environmental impact due to production but lower environmental impact due to use. This is because a leasing firm reduces the cannibalization of new products by removing off-lease products from the market. In our context, this result is instead driven by pay-per-use pricing. In a similar vein, Avci et al. (2015) show that using battery-switching stations and allowing customers to pay only for the use of the batteries may increase the adoption of electric vehicles. However, in their context, this result arises because the switching stations lower the range-inconvenience penalty incurred by the drivers of electric vehicles.

We next focus on the case of strong pooling (i.e., $\gamma = 2$). We begin by characterizing the firm's optimal choice of business model.

PROPOSITION 2. *Under strong pooling: If* $c(e) < C_2(k(e))$*, then the firm offers the hybrid business model, where* $C_2(k(e)) > C_1(k(e))$*. Otherwise, it offers the pure servicizing business model.*

Similar to Proposition 1, the firm prefers to offer the hybrid business model only when the production cost is below a threshold. While under the hybrid business model the firm cannot pool the needs of customers who choose sales instead of the servicizing option, under pure servicizing it pools the needs of all participating customers. As the benefit of pooling is more salient for products with a higher production cost, a pure servicizing business model is more profitable than a hybrid business model when the production cost is high.

We next compare the environmental performance of a hybrid business model under strong pooling to our benchmark of pure sales.

PROPOSITION 3. *Under strong pooling: If the firm offers the hybrid model (i.e., if $c(e) < C_2(k(e))$), then the adoption is higher but the quantity of products and the aggregate usage is lower than under pure sales.*

Recall from Proposition 1 that when there is no pooling, a hybrid business model allows for better price discrimination, which results in higher adoption. This is also true when pooling is strong. However, in this case the increase in adoption does not translate into larger quantity of products because the firm can more effectively pool the customers' needs. Similar to when there is no pooling, the aggregate usage is lower under the hybrid business model due to the lower individual usage of customers who switch from purchasing a product to using it under the servicizing option.

We next compare the environmental performance of a pure servicizing business model under strong pooling to our benchmark of pure sales.

PROPOSITION 4. *Under strong pooling: If the firm offers a pure servicizing business model, i.e., if $c(e) \geq C_2(k(e))$, then the adoption is higher than under pure sales. In addition, the pure servicizing model leads to higher aggregate usage if $c(e) > C_3(k(e))$, and larger quantity of products if $c(e) > C_4(k(e))$, where $C_3(k(e)) < C_4(k(e))$.*

Strong pooling decreases the total production cost, which allows the firm to charge a lower pay-per-use price and further increase the adoption level by reaching inactive customers. For a higher production cost, the firm has to charge a higher price to recoup it, lowering the adoption under the pure sales model and both the adoption and individual usage under the servicizing model. However, the increase in the production cost, and as an extension in the price, is less pronounced under servicizing due to strong pooling. For that reason, the decrease in the adoption and individual usage is also less pronounced. Therefore, when the production cost increases beyond a threshold, $C_3(k(e))$, the aggregate usage is higher under pure servicizing than under pure sales.

Interestingly, Proposition 4 also suggests that even under strong pooling, a pure servicizing model, where the firm pools the needs of all participating customers, may actually require a larger quantity of products than pure sales. This happens when the production cost is sufficiently high (i.e., when $c(e) > C_4(k(e))$). In this case, the decrease in the adoption under pure servicizing is much smaller than the decrease under pure sales, because the firm can better absorb the high production costs under servicizing. Therefore, the adoption is much larger and the firm requires a larger quantity of products to meet the customers' usage needs even with strong pooling.

We next summarize the environmental performance of servicizing business models when they are more profitable under strong pooling.

COROLLARY 2. *Under strong pooling: A hybrid business model is always environmentally superior to pure sales. A pure servicizing business model is environmentally superior if* $c(e) < C_3\big(k(e)\big)$*, but environmentally inferior for products that have the majority of their impact in the use phase, i.e.,* $\omega \doteq \frac{\eta_m}{\eta_m+\eta_u} < \omega_2$*, if* $C_3\big(k(e)\big) \leq c(e) \leq C_4\big(k(e)\big)$*. If* $c(e) > C_4\big(k(e)\big)$*, then a pure servicizing business model is always environmentally inferior to pure sales.*

When pooling is strong, a servicizing business model may be environmentally inferior for products such as servers, cars or washers that have the majority of their impact in the use phase (cf., Fujitsu 2010, Kobayashi 1997, Fishbein et al. 2000). It is also interesting to note that, while a servicizing business model leads to higher environmental impact due to production but lower environmental impact due to use under no pooling (see Corollary 1), under strong pooling it may actually lead to lower environmental impact due to production but higher environmental impact due to use. Corollary 2 also shows that despite strong pooling a pure servicizing business model can lead to higher total environmental impact than pure sales. Therefore, pooling, in contrast to conventional wisdom, can result in servicizing business models being environmentally inferior.

One may also expect that the environmental potential of servicizing would diminish under a hybrid business model as compared to a pure servicizing model. However, the above result shows that when pooling is strong, although the pure servicizing model can be environmentally inferior to pure sales, a hybrid business model is always environmentally superior. This is because, as discussed above, the sales option under the hybrid model reduces the efficacy of pooling and, therefore, limits how much the firm can decrease its pay-per-use price. In sum, our results highlight the importance of accounting for operational characteristics such as the strength of pooling and whether a servicizing business model includes a sales option or not, while assessing the environmental performance of servicizing business models.[4]

We next calibrate our model to illustrate the relative environmental performance of servicizing business models observed in practice. The goal of this exercise is to highlight that the performance

[4] We also find that when a servicizing business model is more profitable, it also leads to higher total customer surplus (details available on request).

of servicizing business models in practice may be contrary to conventional wisdom. In order to do this, we focus on our two main examples, which capture the two extremes of pooling efficacy: i) document management services such as those offered by Xerox, which represents the no pooling case, and ii) cloud services such as those offered by IBM, which represents the strong pooling case.

For each of these cases, we estimate the production and operating costs, and the maximum usage needs in the market. For brevity, we relegate the detailed description of the methods and sources used for the calibration along with the resulting estimates to §A2 in the Appendix. To calculate the production costs, we utilize the reported profit margins from the publicly available financial statements of Xerox and IBM and the average market prices for different models of Xerox multifunction printers and IBM servers. This provides us with a range of values for the production cost, which allows us to discuss how the performance of servicizing may differ for low- versus high-cost products. Using industry reports, we also calculate the operating cost by estimating the cost of toner/ink and electricity per page for printers and the cost of electricity per GB stored for servers. We determine an estimate for the maximum monthly print volume for Xerox's document services customers using the data from Ning et al. (2014) and for the maximum cloud storage needs based on the plans offered by SugarSync, a commercial cloud storage provider. As our model parameters are between zero and one, we normalize the estimates to fit our model. Given the lack of studies estimating the change in usage per unit change in operating cost (b), we assume $b = 1$.

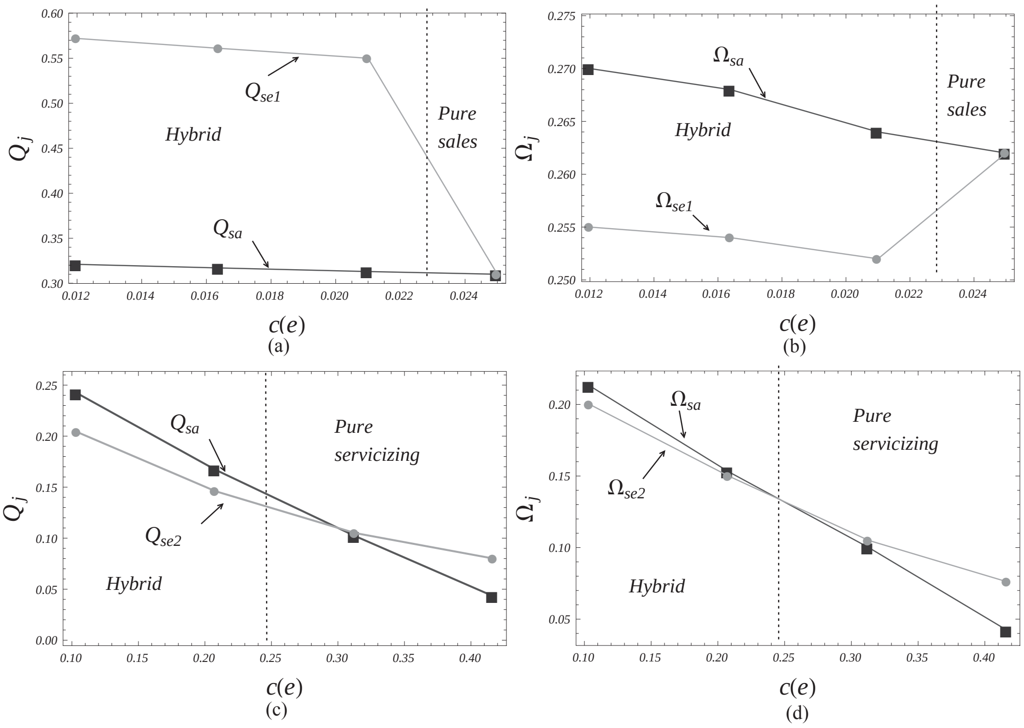
Figure 1 illustrates the firm's optimal business model choice and the relative environmental performance of servicizing by comparing the quantity of products and aggregate usage. For the document management services case, the firm offers a hybrid model as long as the production cost is not very high. Note from panels (a) and (b) that the hybrid model leads to larger quantity of products but the aggregate usage is lower than pure sales. As printers have the majority of their impact in the use phase, this implies that document management services such as those offered by Xerox are environmentally superior. From panels (c) and (d) for the cloud services case, we find that for low-cost servers, the firm offers a hybrid model and it leads to a lower quantity of products and aggregate usage. For high-cost servers, we find that the firm offers a pure servicizing model and it leads to higher quantity of products and aggregate usage. This implies that servicizing is environmentally superior for low-cost servers but environmentally inferior for high-cost servers.

4.2 Product efficiency decisions

We next focus on the firm's product efficiency choice. For analytical tractability, we use $c(e) \doteq c_0 e^2$ and $k(e) \doteq k_0(1-e)$ as the specifications for the production and operating costs, respectively.[5] We next analyze the effect of product efficiency on the customers' usage under the different options.

[5] We can numerically show that our structural results hold for $k(e) = k_0(1-e)^2$, which is convex in efficiency. Our results also hold for a production cost specification quadratic in the quantity, which captures economies of scale.

Figure 1 Comparisons for the quantity of products Q_j and aggregate usage Ω_j for the servicizing business model ($j = se\gamma$) and the benchmark pure sales model ($j = sa$).



Note. Solid black squares denote the pure sales model and gray circles denote a servicizing business model. Panels (a)-(b) are based on the normalized estimates for document management services with $\gamma = 1$, $k = 0.003$ and $b = 1$. The firm offers a hybrid business model below the dashed vertical line and pure sales above it. Panels (c)-(d) are based on the normalized estimates for cloud services with $\gamma = 2$, $k = 4.79 \times 10^{-5}$ and $b = 1$. The firm offers a hybrid business model below the dashed vertical line and pure servicizing above it.

PROPOSITION 5. *Under the sales option, an individual customer's usage always increases in the product efficiency. The increase in the customer usage due to higher efficiency, is higher under the sales option than under the servicizing option. If $c_0 > \widehat{C}^i_\gamma(k_0)$, an individual customer's usage under the servicizing option actually decreases in the product efficiency, for $i \in \{p, h\}$.*

Higher product efficiency results in lower operating cost, which enables the firm to charge a higher sales price for a more efficient product. However, under the sales option the customer's usage, $q^*_{sa}(\theta; f^{i*}_{sa}(e), e) = \theta - bk(e)$, does not directly depend on the sales price, and for that reason it always increases in the product efficiency. This is in line with conventional wisdom according to which, as products become more efficient, customer usage increases. In other words, the rebound effect takes place (Greening et al. 2000). However, under the servicizing option, if the production cost is high, a more efficient product may lead to lower customer usage. The reason is that under the servicizing option, customers' usage, $q^*_{se}(\theta; f^{i*}_{se}(e), e) = \theta - b\left(f^{i*}_{se}(e) + k(e)\right)$ for $i \in \{p, h\}$, depends on both the operating cost and the pay-per-use price. The firm charges a higher pay-per-use price for a more efficient product in order to recoup the production cost. This implies that in addition to the direct positive effect because of the lower operating cost, a higher efficiency exerts an indirect negative effect on the customer usage. As the production cost increases, the firm charges an even higher pay-per-use price. Therefore, if the production cost is sufficiently high, then the negative effect of a higher pay-per-use price on the individual customer usage dominates. This leads customer usage to decrease in product efficiency, which means that the rebound effect may not take place under the servicizing option. This finding provides a novel mechanism that may deter the rebound effect from taking place, and make servicizing business models environmentally superior.

We next focus on comparing the profit-maximizing efficiency choices between a servicizing business model and pure sales model. The firm's problem is to choose the product efficiency $e_{sa}^{p^*} \in [0,1]$ that maximizes $\widetilde{\Pi}_{sa}^p$ under pure sales. We assume $c_0 < \frac{1}{2}$ to ensure that the pure sales model has a strictly positive profit for all $e \in [0,1]$. For the sake of analytical tractability, we assume $b = 1$ for the next result, which can be numerically shown to hold for any $b > 0$ (details available on request). In general, the firm's design problem is to choose the product efficiency $e_\gamma^* \in [0,1]$ that maximizes $\widetilde{\Pi}_\gamma^*(e)$, where $\widetilde{\Pi}_\gamma^*(e) = \max\left\{\widetilde{\Pi}_{sa}^p(e), \widetilde{\Pi}_{se\gamma}^p(e), \widetilde{\Pi}_\gamma^h(e)\right\}$. To avoid uninteresting comparisons when the firm chooses the pure sales model under no pooling, we restrict our attention to $k_0 < K_1(c_0)$, which ensures that the hybrid business model is more profitable than pure sales for all $e \in [0,1]$. Under strong pooling, we restrict our attention to $k_0 < K_2(c_0)$ for analytical tractability and brevity.[6]

Based on the proposed arguments in practice, one would expect the firm to offer products with higher efficiency under a servicizing business model. The rationale behind this argument is that the firm has a greater incentive to reduce operating costs by providing products with higher efficiency as its revenue is based on the customer usage. However, the next result shows that a servicizing business model may actually lead to products with lower efficiency.

PROPOSITION 6. *Under no pooling, a servicizing business model leads to lower efficiency than pure sales (i.e.,* $e_1^* \le e_{sa}^{p^*}$*). However, under strong pooling, a servicizing business model leads to higher efficiency than pure sales (i.e.,* $e_{sa}^{p^*} \le e_2^*$*).*

A higher product efficiency leads to a lower operating cost and a higher unit production cost. Therefore, the firm's decision to invest in higher efficiency depends on the extent to which it benefits from a higher aggregate usage (due to a lower operating cost) and the associated increase in the total production cost. Under a servicizing business model, the firm directly benefits from a higher aggregate usage because it directly increases the revenue. However, under sales the firm benefits only indirectly from higher aggregate usage because its revenue does not directly depend on it.

[6] It can be numerically shown that our results hold even when the conditions $k_0 < K_1(c_0)$ and $k_0 < K_2(c_0)$ are relaxed.

Under no pooling, a servicizing business model leads to a larger quantity of products but lower aggregate usage than pure sales (see Proposition 1). Although the firm would prefer to increase the aggregate usage by increasing the efficiency, this would lead to a significantly higher total production cost. The increase in the total production cost dominates, and for that reason the firm chooses a lower efficiency for a servicizing business model under no pooling.

Strong pooling reduces the quantity of products required to meet customer needs and, consequently, lowers the total production cost. This makes investing in efficiency more attractive for the firm. Recall that when the unit production cost is low, a servicizing business model leads to smaller quantity of products and lower aggregate usage than pure sales (see Propositions 3 and 4). This implies that for low production costs the firm has a greater incentive to invest in higher efficiency under a servicizing business model in order to increase aggregate usage. As the unit production cost increases, the firm charges a higher price. This lowers the total adoption under both a pure sales and a servicizing business model. However, under a servicizing business model a higher unit production cost also exerts a direct negative effect on the individual usage (this is not the case under a pure sales model; see Lemma 1). For that reason, the firm's incentive to increase the aggregate usage is greater for a higher production cost. Therefore, the firm chooses a higher product efficiency even when the quantity of products and the associated total production cost are higher (see Proposition 4).

We next discuss the effect of the optimal product efficiency on the relative environmental performance of servicizing business models. The environmental performance depends on the comparisons of the quantity of products and aggregate usage at the optimal efficiencies and on how the per-unit environmental impact depends on the product efficiency. While comparing the quantity of products and aggregate usage in this case is analytically intractable, we numerically verify that our structural results regarding their comparisons continue to hold. In particular, under no pooling as in Proposition 1, the hybrid business model leads to a larger quantity of products and lower aggregate usage than pure sales. Similarly, under strong pooling as in Propositions 3 and 4, the hybrid business model leads to a smaller quantity of products and aggregate usage, whereas the pure servicizing model can lead to higher quantity of products and aggregate usage.

Note that the per-unit of usage impact, η_u, may be lower for a product with higher efficiency due to the smaller amount of energy, raw materials, or resources required during its use. Recall that for no pooling the aggregate usage is lower under a servicizing business model (see Proposition 1). In addition, the firm chooses a lower efficiency under a servicizing business model (see Proposition 6), which results in a higher η_u. This implies that under no pooling the relative environmental performance of a servicizing business model worsens. Similarly, under strong pooling, the firm chooses a higher efficiency under a servicizing business model and therefore, its relative environmental performance improves. The per-unit environmental impact due to production, η_m, may be higher for a product with higher efficiency, as manufacturing the product may require more expensive material and processing. The effect of this is that the relative environmental performance of a servicizing business model improves under no pooling but worsens under strong pooling.

5. Model Extensions and Discussion of Assumptions

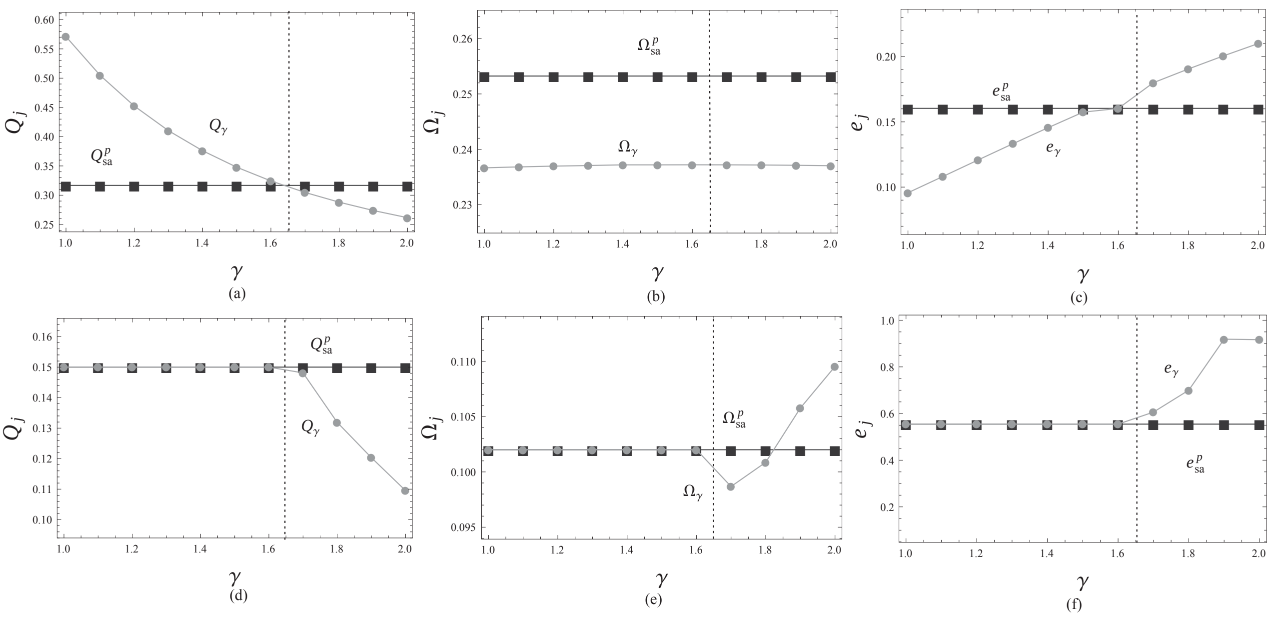
We now discuss the implications of relaxing some of the assumptions used in our main analysis and provide extensions that capture additional considerations relevant to our context.

5.1 Results for a general $\gamma \in (1,2)$.

Throughout our main analysis we focused on the two extreme cases of pooling represented by $\gamma = 1$ (no pooling) and $\gamma = 2$ (strong pooling). While solving for the firm's pricing and efficiency decisions under a general $\gamma \in (1,2)$ is analytically intractable, we numerically analyze the relative performance of servicizing business models for the intermediate range of $\gamma \in (1,2)$. The optimal business model choice for a general γ can be structurally more complex than the two extremes discussed in Propositions 1 and 3. Overall, the hybrid business model is optimal for low production costs. The hybrid and pure servicizing models become more attractive for a stronger level of pooling. The pure servicizing business model is optimal only when pooling is sufficiently strong and production cost is high. As γ increases (i.e., as pooling becomes stronger), the optimal business model choice may switch from the pure sales to the hybrid model and eventually to the pure servicizing model.

With respect to the relative environmental performance of servicizing business models for a general $\gamma \in (1,2)$, we find the following: There exists a threshold value of γ below which the results are structurally similar to our no pooling case ($\gamma = 1$) and above which they are structurally similar to our strong pooling case ($\gamma = 2$). Figure 2 illustrates a representative example from our numerical analysis. It can be seen from panels (a)-(c) that for lower values of γ (i.e., for values below the dashed vertical line), the servicizing business model leads to a larger quantity of products but lower aggregate usage and product efficiency than pure sales. This is similar to our results under the no pooling case (see Propositions 1 and 6). For higher values of γ (i.e., for values above the dashed vertical line), the hybrid business model leads to a smaller quantity of products and aggregate usage but higher product efficiency than pure sales. This is similar to our strong pooling case (see Propositions 3 and 6). It can be seen from panels (d)-(f) that for higher values of γ (above the dashed vertical line), the hybrid model leads to a smaller quantity of products and aggregate usage than pure sales, and the pure servicizing model leads to a smaller quantity of products but higher aggregate usage. Both servicizing models lead to higher efficiency than pure sales. This is similar to our results under the strong pooling case (see Propositions 3, 4 and 6).

Figure 2 Comparisons for a general value of $\gamma \in [1,2]$. The dashed vertical line denotes the threshold value of γ below which the results are similar to the no pooling case and above which they are similar to the strong pooling case.



Note. Solid black squares denote the pure sales business model and gray circles denote a servicizing business model. In panels (a)-(c), $c_0 = 0.1$, $k_0 = 0.05$, $b = 1$, and the firm offers a hybrid business model for all γ. In panels (d)-(f), $c_0 = 0.3$, $k_0 = 0.8$, $b = 1$, and the firm offers a pure sales model below the dashed line ($\gamma < 1.7$) and a servicizing business model above it. In particular, the firm offers a hybrid model for $1.7 \le \gamma < 1.9$ and a pure servicizing model for $1.9 \le \gamma \le 2$.

5.2 Alternative model of pooling.

In our main analysis, we capture the key characteristics of pooling with a parsimonious model that maintains analytical tractability. We now consider a model of pooling using an alternative queueing-based approach (cf., Bellos et al. 2013).

In particular, assume that the firm maintains a pool of Q products to ensure a service level $\rho \in (0,1)$, which is exogenous and chosen based on some external conditions such as an industry standard. Let the size of the customer population be generalized to $N > 1$. Customers request the use of a product according to a Poisson process. If a customer does not find a product available, then his request is met the next time a product is available. The customer's net utility from a usage q_{se} is given by $U_{se}(q_{se};\theta, f_{se}, e) = V_\theta(q_{se}) - b\big(k(e) + f_{se}\big)q_{se}$. The optimal usage of an individual customer remains the same as in our basic model, $q^*_{se}(\theta; f_{se}, e) = \theta - b\big(k(e) + f_{se}\big)$. Assume that each time a customer requests and receives a product, the expected usage is τ. If customers with $\theta \in [\Theta_j, \Theta_i]$ choose the servicizing option, then the rate of requests faced by the firm is given by $\lambda = N\int_{\Theta_j}^{\Theta_i} \frac{q^*_{se}(\theta; f_{se}, e)d\theta}{\tau}$.

In this framework, the firm's operational system resembles a closed queueing network with Q jobs. Following the literature (see Whitt 1984, Toktay et al. 2000), an open-network counterpart of the closed network can be constructed, in which case from Bellos et al. (2013), the quantity of products required by the firm is then given by

$$Q = \rho\left(\frac{1}{1-\rho} + \lambda\tau\right) = \rho\left(\frac{1}{1-\rho} + N\int_{\Theta_j}^{\Theta_i} q_{se}^*(\theta; f_{se}, e)d\theta\right) = \rho\left(\frac{1}{1-\rho} + \frac{N\big(n_{se}(f_{se}; e)\big)^2}{2}\right).$$

It can be seen that the above specification has the same properties as the one used in our main analysis, in that the quantity of products required is convex increasing in the adoption n_{se}, and it is also similar in structure to our special case of strong pooling ($\gamma = 2$).

5.3 Economies of scale in pooling.

The specification for the quantity of products in our main analysis assumes that the efficacy of pooling decreases in the adoption (i.e., the quantity of products required is convex in the adoption). One could also consider a situation where the firm enjoys economies of scale, in which case the efficacy of pooling increases in the adoption level (i.e., the quantity of products required is concave in the adoption). For example, this may happen if the increasing adoption faced by the firm stems from the consolidation of multiple pools from different locations. While analyzing this case is analytically intractable in our setting, we numerically investigate whether our results hold for such a scenario. We do so by utilizing an alternative formulation, $Q_{seg}^i(\cdot) = n_{se}(\cdot) - \frac{(n_{se}(\cdot))^{\frac{1}{g}+1}}{\frac{1}{g}+1}$, which is concave in the adoption level, and where $g \geq 0$ captures the strength of the pooling effect. Similar to the specification used in our main analysis, the quantity of products required is increasing in the adoption level and decreasing in the strength of pooling. The no pooling case is captured by $g \to 0$ because then $Q_{seg}^i(\cdot) \to n_{se}(\cdot)$.

We utilize $Q_{seg}^i(\cdot)$ in our numerical analysis to analyze the effect of a concave pooling specification on our results. For lower values of g (i.e., for weak pooling), we find that the results are structurally similar to those of our no pooling case. That is, the hybrid business model leads to a larger quantity of products, but lower aggregate usage and product efficiency (as in Propositions 1 and 6). For higher values of g (i.e., when the pooling effect is stronger), we find that the hybrid model leads to lower aggregate usage (as in Proposition 3 for our strong pooling case), but the quantity of products can be larger than the benchmark of pure sales. The result that the pure servicizing model can lead to higher aggregate usage and larger quantity of products still holds (as in Proposition 4). However, in the presence of economies of scale, the aggregate usage and quantity of products under pure servicizing is higher for smaller values of the production cost. This implies that economies of scale worsens the relative environmental performance of servicizing business models. The reason is that as the efficacy of pooling increases in the adoption level, the firm has a greater incentive to further reach customers with lower usage needs. This leads to greater adoption, a larger quantity of products, and consequently, higher total production cost. As a result, in contrast to Proposition 6, the product efficiency can be lower under a servicizing business model even with strong pooling.

Overall, these findings imply that our main results regarding the detrimental effect of pooling continue to hold in the presence of economies of scale, which further worsens the environmental performance of servicizing.

5.4 Alternative utility functions.

In our main analysis, the functional form for customers' utility is quadratic in usage, which leads the optimal usage to be linear in the pay-per-use price (see Lemma 1). This allows us to obtain the optimal decisions in an analytically tractable manner. We now discuss the robustness of our results when the customers' utility is such that the resulting optimal usage is nonlinear in the pay-per-use price. In particular, we consider the net utility of customer θ under the sales and servicizing option to be $U^i_{sa}(q^i_{sa};\theta, f^i_{sa}, e) = q_{sa}(\theta - k)^{z+1} - \frac{(q^i_{sa})^2}{2} - f^i_{sa}$ and $U^i_{se}(q^i_{se};\theta, f^i_{se}, e) = q_{se}(\theta - f^i_{se} - k)^{z+1} - \frac{(q^i_{se})^2}{2}$, where $z \geq 0$.[7] We obtain $q^{i*}_{sa}(\theta; f^i_{sa}, e) = \big(\theta - bk(e)\big)^{z+1}$ and $q^{i*}_{se}(\theta; f^i_{se}, e) = \big(\theta - b(f^i_{se} + k(e))\big)^{z+1}$, which are nonlinear for $z > 0$. Given that this renders our analysis analytically intractable, we numerically investigate whether our results hold for functional forms with $z \in \{1, 2\}$ (i.e., quadratic and cubic optimal usage functions). We find that our results in Proposition 4 regarding the environmental performance of pure servicizing business models and our results in Proposition 6 regarding the comparison of optimal efficiencies continue to hold. However, the environmental performance of hybrid business models can worsen. Specifically, in contrast to Propositions 1 and 3, the hybrid business model can lead to higher aggregate usage and larger quantity of products. This is because the pay-per-use price now has a nonlinear effect on the optimal usage, leading the firm to choose a lower price to compensate customers, which results in a larger adoption.

5.5 A lower operating cost under servicizing.

Our model assumes that customers incur the operating cost, $k(e)$, under both the sales and the servicizing option. However, in practice the firm may bear the operating cost under the servicizing option. Moreover, the operating cost may be lower when faced by the firm, than when faced by the customers. This may be due to economies of scale or because the firm has greater expertise in activities such as maintenance and repair. In this case, a lower operating cost will allow the firm to charge a lower pay-per-use price which in turn will increase adoption and aggregate usage. Therefore, although a servicizing business model will be relatively more profitable, its environmental performance will deteriorate.

[7] The case with $z = 0$ is identical to the functional form used in our main analysis.

6. Conclusions

Several environmental groups and agencies have argued that servicizing can be environmentally superior to sales (White et al. 1999, Fischer et al. 2012). While these claims have gained traction in practice, the environmental potential of such models is not clear (cf., U.S. Environmental Protection Agency 2009, p. 19). Motivated by this, our research offers insights for firms and environmental agencies regarding when and why a servicizing business model is both more profitable and environmentally beneficial.

We show that the environmental performance of servicizing depends on structural characteristics such as pay-per-use pricing and degree of pooling, and on whether the firm offers servicizing through a hybrid or pure servicizing model. Under no pooling, a hybrid business model leads to a larger quantity of products but lower aggregate usage. Therefore, it is environmentally superior only for products that have the majority of their environmental impact in the use phase. In contrast, under strong pooling, a hybrid model is environmentally superior to pure sales. Interestingly, a pure servicizing model is environmentally inferior for high production costs because it leads to a larger quantity of products, even with strong pooling. We also show that, in contrast to arguments in practice, a firm offers products with higher efficiency only under servicizing models with strong pooling. Finally, we identify a novel mechanism regarding why servicizing can be environmentally superior. Under servicizing, a more efficient product can actually lead to lower customer usage, which implies that servicizing may act as a mechanism to moderate the rebound effect.

In order to capture the main trade-offs faced by the firm when considering servicizing we developed a parsimonious model, which focused on pay-per-use pricing, pooling, and whether both sales and servicizing options are offered, as the most common operational characteristics of servicizing models. In practice, the firm's and customers' decisions under a servicizing business model may be affected by additional factors. For example, there can be uncertainty in customers' usage needs, inconvenience costs associated with having to wait for a product to become available, and "anxieties" associated with the possibility of the product not being functional or available when required. These factors can make it important for the firm to also account for operational considerations such as risk pooling and demand-supply mismatch. A promising direction for future research is to assess how these factors influence the economic and environmental performance of servicizing.

In practice, firms can possibly enjoy lower product recovery and reuse costs under servicizing as they maintain ownership of the products. This can be interpreted in our model as a lower unit production cost for the units provided through servicizing, which would lead to higher adoption and aggregate usage, and consequently improve the relative profitability but worsen the relative environmental performance of servicizing. Finally, although we did not consider competition between firms, we can conjecture about its effect on our results. In particular, we expect that competition will put downward pressure on the firms' pricing decisions, resulting in greater adoption and usage. Thus, competition will lead to higher total environmental impact under each of the business models. We also expect servicizing business models to be more attractive to a firm than pure sales because pooling helps reduce the production cost and maintain profit margins. Nevertheless, understanding how competition influences the relative environmental performance of servicizing remains a promising direction for future research.

Appendix

A1. Proofs

Proof of Lemma 1. We first begin by determining a customer's optimal usage decision under the sales and servicizing options. The utility-maximization problem of a customer θ under the sales option is given by $\max_{q^i_{sa}\geq 0} U^i_{sa}(q^i_{sa};\theta, f^i_{sa}, e) = \frac{1}{b}\left(\theta q^i_{sa} - \frac{\left(q^i_{sa}\right)^2}{2}\right) - k(e)q^i_{sa} - f^i_{sa}$, where $U^i_{sa}(q^i_{sa};\theta, f^i_{sa}, e)$ is strictly concave in q^i_{sa}. Solving the first-order condition, we obtain $q^{i^*}_{sa}(\theta; f^i_{sa}, e) = \theta - bk(e)$, and $U^i_{sa}(q^{i^*}_{sa};\theta, f^i_{sa}, e) = \frac{\left(\theta - bk(e)\right)^2}{2b} - f^i_{sa}$. The utility-maximization problem of a customer θ under servicizing is given by $\max_{q^i_{se}\geq 0} U^i_{se}(q^i_{se};\theta, f^i_{se}, e) = \frac{1}{b}\left(\theta q^i_{se} - \frac{\left(q^i_{se}\right)^2}{2}\right) - (f^i_{se} + k(e))q^i_{se}$, where $U^i_{se}(q^i_{se};\theta, f^i_{se}, e)$ is strictly concave in q^i_{se}. Solving the first-order condition, we obtain $q^{i^*}_{se}(\theta; f^i_{se}, e) = \theta - b(f^i_{se} + k(e))$, and $U^i_{se}(q^{i^*}_{se};\theta, f^i_{se}, e) = \frac{\left(\theta - b(k(e)+f^i_{se})\right)^2}{2b}$.

Under the pure sales model, the marginal customer who is indifferent between purchasing a product and remaining active is determined by solving $U^p_{sa}(q^{p^*}_{sa};\theta, f^p_{sa}, e) = 0$ for θ, which gives $\theta = \Theta^p_{sa} \doteq \sqrt{2bf^p_{sa}} + bk(e)$. As $U^p_{sa}(q^{p^*}_{sa};\theta, f^p_{sa}, e)$ is increasing in θ, customers with $\theta \in [\Theta^p_{sa}, 1]$ purchase a product and the rest remain inactive. The resulting adoption is given by $n^p_{sa}(f^p_{sa}; e) = 1 - bk(e) - \sqrt{2bf^p_{sa}}$. Note that $q^{p^*}_{sa}$ is always positive for $\theta \geq \Theta^p_{sa}$. Similarly, under the pure servicizing model, the marginal customer who is indifferent between participating and remaining active is determined by solving $U^p_{se}(q^{p^*}_{se};\theta, f^p_{se}, e) = 0$ for θ, which gives $\theta = \Theta^p_{se} \doteq b(f^p_{se} + k(e))$. As $U^h_{se}(q^{h^*}_{se};\theta, f^h_{se}, e)$ is increasing in θ, customers with $\theta \in [\Theta^p_{se}, 1]$ choose servicizing and the rest remain inactive. The resulting adoption is given by $n^p_{se}(f^p_{se}; e) = 1 - bk(e) - bf^p_{se}$. Note that $q^{p^*}_{se} \geq 0$ for $\theta \geq \Theta^p_{se}$.

Under the hybrid business model, customers choose between the sales and servicizing options, or remain inactive. The net utility from each of these options is given by: $U^h_{sa}(q^{h^*}_{sa};\theta, f^h_{sa}, e) = \frac{\left(\theta - bk(e)\right)^2}{2b} - f^h_{sa}$, $U^h_{se}(q^{h^*}_{se};\theta, f^h_{se}, e) = \frac{\left(\theta - bk(e) - bf^h_{se}\right)^2}{2b}$ and 0, respectively. It is straightforward to show that $U^h_{sa}(q^{h^*}_{sa};\theta, f^h_{sa}, e) - U^h_{se}(q^{h^*}_{se};\theta, f^h_{se}, e)$, and $U^h_{se}(q^{h^*}_{se};\theta, f^h_{se}, e)$ are strictly increasing in θ. This implies that customers who choose the sales option have higher θ than those who choose the servicizing option, who in turn have higher θ than those who remain inactive. Let the marginal customer who is indifferent between the sales and the servicizing option and, between servicizing and remaining inactive be denoted by Θ_1^h and Θ_2^h, respectively. The values of Θ_1^h and Θ_2^h are found by solving $U_{sa}^h(q_{sa}^{h^*};\theta,f_{sa}^h,e)=U_{se}^h(q_{se}^{h^*};\theta,f_{se}^h,e)$ and $U_{se}^h(q_{se}^{h^*};\theta,f_{se}^h,e)=0$ for θ, which gives $\theta=\Theta_1^h\doteq\frac{2f_{sa}^h+2bk(e)f_{se}^h+b(f_{se}^h)^2}{2f_{se}^h}$ and $\theta=\Theta_2^h\doteq b(f_{se}^h+k(e))$. Therefore, customers in $\theta\in(\Theta_1^h,1]$ choose sales, customers in $\theta\in[\Theta_2^h,\Theta_1^h]$ choose servicizing and, customers in $\theta\in[0,\Theta_2^h)$ remain inactive. Note that $U_{sa}^h(q_{sa}^{h^*};\theta,f_{sa}^h,e)\geq 0$ for all $\theta\geq\Theta_1^h$ and $U_{se}^h(q_{se}^{h^*};\theta,f_{se}^h,e)\geq 0$ for all $\theta\geq\Theta_2^h$. The adoption of sales under the hybrid model is given by $n_{sa}^h(f_{sa}^h,f_{se}^h;e)\doteq 1-\Theta_1^h=\frac{f_{se}^h\left(2-2bk(e)-bf_{se}^h\right)-2f_{sa}^h}{2f_{se}^h}$ and that of servicizing is given by $n_{se}^h(f_{sa}^h,f_{se}^h;e)=\frac{2f_{sa}^h-b(f_{se}^h)^2}{2f_{se}^h}$. Finally, note that for $n_{sa}^h(f_{sa}^h,f_{se}^h,e),n_{se}^h(f_{sa}^h,f_{se}^h,e)>0$, we need $\frac{b(f_{se}^h)^2}{2}<f_{sa}^h<\frac{f_{se}^h\left(2-2bk(e)-bf_{se}^h\right)}{2}$.□

Proof of Proposition 1 and Corollary 1. In the interest of expositional brevity, we suppress the dependence of operating and production costs on the efficiency. In addition, we focus on no pooling and suppress the notation in the subscript for $\gamma=1$.

Under pure sales, the firm's pricing problem is given by $\max_{f_{sa}^p}\Pi_{sa}^p(f_{sa}^p;e)=\left(f_{sa}^p-c\right)n_{sa}^p(f_{sa}^p;e)=\left(f_{sa}^p-c\right)\left(1-bk(e)-\sqrt{2bf_{sa}^p}\right)$. $\Pi_{sa}^p(f_{sa}^p;e)$ is strictly concave in f_{sa}^p because $\Pi_{sa}^{p''}(f_{sa}^p;e)=\frac{-\sqrt{b}(3f_{sa}^p+c)}{2\sqrt{2}(f_{sa}^p)^{3/2}}<0$. Solving the first-order condition, we obtain $f_{sa}^{p^*}(e)=\frac{(1-bk)^2+3bc+(1-bk)\sqrt{(1-bk)^2+6cb}}{9b}>0$. Substituting the optimal price, we get $\widetilde{n}_{sa}^p(e)\doteq n_{sa}^p(f_{sa}^{p^*}(e);e)=\frac{2(1-bk)-\sqrt{(1-bk)^2+6bc}}{3}$ (where $\widetilde{Q}_{sa}^p(e)=\widetilde{n}_{sa}^p(e)$), $\widetilde{\Omega}_{sa}^p(e)\doteq\Omega_{sa}^p(f_{sa}^{p^*}(e);e)=\frac{9(1-bk)^2-\left((1-bk)+\sqrt{(1-bk)^2+6bc}\right)^2}{18}$ and, $\widetilde{\Pi}_{sa}^p(e)\doteq\Pi_{sa}^p(f_{sa}^{p^*}(e);e)=\frac{\left(2(1-bk)-\sqrt{(1-bk)^2+6bc}\right)\left(-6bc+(1-bk)\left(1-bk+\sqrt{(1-bk)^2+6bc}\right)\right)}{27b}$. Note that $\widetilde{\Pi}_{sa}^p(e),\widetilde{n}_{sa}^p(e)>0$ if and only if $c<\frac{(1-bk)^2}{2b}$.

Under pure servicizing, the firm's pricing problem is given by $\max_{f_{se}^p}\Pi_{se}^p(f_{se}^p;e)=f_{se}^p\Omega_{se}^p(f_{se}^p;e)-cQ_{se}^p(f_{se}^p;e)$, where $\Omega_{se}^p(f_{se}^p;e)=\int_{\Theta_{se}^p}^1 q_{se}^{p^*}(\theta)d\theta=\frac{(1-bf_{se}^p-bk)^2}{2}$ and $Q_{se}^p(f_{se}^p;e)=n_{se}^p(f_{se}^p;e)=(1-bf_{se}^p-bk)$. The firm's profit is positive if and only if $F_1\doteq\frac{(1-bk)-\sqrt{(1-bk)^2-8bc}}{2b}<f_{se}^p<F_2\doteq\frac{(1-bk)+\sqrt{(1-bk)^2-8bc}}{2b}$, where $F_1<F_2$ can hold if and only if $c<\frac{(1-bk)^2}{8b}\left(<\frac{(1-bk)^2}{2b}\right)$. The solution to the first-order condition yields only one local optima such that the firm's profit is positive, given by $f_{se}^p=F^A\doteq\frac{2(1-bk)-\sqrt{(1-bk)^2-6bc}}{3b}$, which is real-valued under the condition for positive profitability ($c<\frac{(1-bk)^2}{8b}$). As $\Pi_{se}^{p''}(F^A;e)=-\sqrt{(1-bk)^2-6bc}<0$, $\Pi_{se}^p(F_1;e)=0$, and $\Pi_{se}^p(F_2;e)=0$, F^A is the unique maximizer, i.e., $f_{se}^{p^*}(e)=F^A\doteq\frac{2(1-bk)-\sqrt{(1-bk)^2-6bc}}{3b}$. At the optimal price, $\widetilde{n}_{se}^p(e)\doteq n_{se}^p(f_{se}^{p^*};e)=\frac{1-bk+\sqrt{(1-bk)^2-6bc}}{3}$ (where $\widetilde{Q}_{se}^p(e)=\widetilde{n}_{se}^p(e)$), $\widetilde{\Omega}_{se}^p(e)\doteq\Omega_{se}^p(f_{se}^{p^*};e)=\frac{\left(1-bk+\sqrt{(1-bk)^2-6bc}\right)^2}{18}$ and $\widetilde{\Pi}_{se}^p(e)\doteq\Pi_{se}^p(f_{se}^{p^*};e)=\frac{\left(-12bc+\left(1-bk\right)\left(1-bk+\sqrt{(1-bk)^2-6bc}\right)\right)\left(1-bk+\sqrt{(1-bk)^2-6bc}\right)}{54b}$.

Under the hybrid business model, the firm's pricing problem is given by $\max_{f_{sa}^h,f_{se}^h}\Pi^h(f_{sa}^h,f_{se}^h;e)=\Pi_{sa}^h(f_{sa}^h,f_{se}^h;e)+\Pi_{se}^h(f_{sa}^h,f_{se}^h;e)=(f_{sa}^h-c)n_{sa}^h(f_{sa}^h,f_{se}^h;e)+f_{se}^h\Omega_{se}^h(f_{sa}^h,f_{se}^h;e)-cn_{se}^h(f_{sa}^h,f_{se}^h;e)$, where $\Omega_{se}^h(f_{sa}^h,f_{se}^h;e)=\frac{\left(2f_{sa}^h-b(f_{se}^h)^2\right)^2}{8(f_{se}^h)^2}$, $n_{sa}^h(f_{sa}^h,f_{se}^h;e)=\frac{f_{se}^h(2-2bk-bf_{se}^h)-2f_{sa}^h}{2f_{se}^h}$, and $n_{se}^h(f_{sa}^h,f_{se}^h;e)=\frac{2f_{sa}^h-b(f_{se}^h)^2}{2f_{se}^h}$. The solution to the first-order conditions yields only one local optima that can be a maximizer, given by $f_{sa}^{h^*}=\frac{2\left(60bc+(1-bk)(26(1-bk)+\sqrt{(1-bk)^2-30bc})\right)}{225b}$ and $f_{se}^{h^*}=\frac{2\left(4(1-bk)-\sqrt{(1-bk)^2-30bc}\right)}{15b}$, which is a maximizer if and only if $c<\frac{(1-bk)^2}{30b}$. In addition, $n_{sa}^h(f_{sa}^{h^*},f_{se}^{h^*};e),n_{se}^h(f_{sa}^{h^*},f_{se}^{h^*};e)>$

0 holds only if $c < \frac{(1-bk)^2}{30b}$. Therefore, it is the unique maximizer under this condition. At the optimal prices, we have $\widetilde{n}^h_{sa}(e) \doteq n^h_{sa}(f^{h^*}_{sa}, f^{h^*}_{se}; e) = \frac{\left(4(1-bk)-\sqrt{(1-bk)^2-30bc}\right)}{15}$, $\widetilde{n}^h_{se}(e) \doteq n^h_{se}(f^{h^*}_{sa}, f^{h^*}_{se}; e) = \frac{\left((1-bk)+\sqrt{(1-bk)^2-30bc}\right)}{5}$, $\widetilde{\Omega}^h_{se} \doteq \Omega^h_{se}(f^{h^*}_{sa}, f^{h^*}_{se}; e) = \frac{\left((1-bk)\left((1-bk)+\sqrt{(1-bk)^2-30bc}\right)-15bc\right)}{25}$, $\widetilde{\Omega}^h_{sa} \doteq \Omega^h_{sa}(f^{h^*}_{sa}, f^{h^*}_{se}; e) = \frac{\left(30bc+(1-bk)\left(103(1-bk)-22\sqrt{(1-bk)^2-30bc}\right)\right)}{450}$, and $\widetilde{\Pi}^h(e) \doteq \Pi^h(f^{h^*}_{sa}, f^{h^*}_{se}; e) = \frac{2(1-bk)^2\left(26(1-bk)+\sqrt{(1-bk)^2-30bc}\right)-15bc\left(21(1-bk)+4\sqrt{(1-bk)^2-30bc}\right)}{675b}$. The total adoption (and thus the quantity of products) and aggregate usage are given by $\widetilde{Q}^h(e) = \widetilde{n}^h(e) \doteq \widetilde{n}^h_{sa}(e) + \widetilde{n}^h_{se}(e) = \frac{\left(7(1-bk)+2\sqrt{(1-bk)^2-30bc}\right)}{15}$ and $\widetilde{\Omega}^h(e) \doteq \widetilde{\Omega}^h_{sa}(e) + \widetilde{\Omega}^h_{se}(e) = \frac{\left((1-bk)\left(121(1-bk)-4\sqrt{(1-bk)^2-30bc}\right)-240bc\right)}{450}$.

We now examine the firm's optimal choice of business model under no pooling. Recall that the hybrid business model is valid (i.e., $\widetilde{n}^h_{se}, \widetilde{n}^h_{sa} > 0$) only if $c < \frac{(1-bk)^2}{30b}$. The pure servicizing model and pure sales model lead to strictly positive profit only if $c < \frac{(1-bk)^2}{8b}$, and $c < \frac{(1-bk)^2}{2b}$, respectively. We first begin by comparing the profit under the pure sales and pure servicizing models. $\widetilde{\Pi}^p_{sa} - \widetilde{\Pi}^p_{se}$ is increasing in c because $\frac{d(\widetilde{\Pi}^p_{sa}-\widetilde{\Pi}^p_{se})}{dc} = \frac{-1+bk+\sqrt{(1-bk)^2-6bc}+\sqrt{(1-bk)^2+6bc}}{3} > 0$, and zero at $c = 0$, which implies that $\widetilde{\Pi}^p_{sa} \geq \widetilde{\Pi}^p_{se}$. To compare the profit between the hybrid and pure sales model, let $z_1(c) \doteq \widetilde{\Pi}^h - \widetilde{\Pi}^p_{sa}$, where $z_1(c)$ is decreasing in c because $\frac{dz_1(c)}{dc} = \frac{3(1-bk)-2\sqrt{(1-bk)^2-30bc}-5\sqrt{(1-bk)^2+6bc}}{15} < 0$ for $c \leq \frac{(1-bk)^2}{30b}$, positive at $c = 0$ and negative at $c = \frac{(1-bk)^2}{30b}$. This implies that there exists a threshold $C_1(k)$ obtained by solving $z_1(c) = 0$, such that if $c < C_1(k)\left(< \frac{(1-bk)^2}{30b}\right)$, then $z_1(c) > 0$ or $\widetilde{\Pi}^h > \widetilde{\Pi}^p_{sa}$, otherwise $z_1(c) \leq 0$ or $\widetilde{\Pi}^h \leq \widetilde{\Pi}^p_{sa}$.

We next compare the adoption, quantity of products, and aggregate usage between the hybrid business model and pure sales, when the hybrid business model is more profitable, i.e., $c < C_1(k)$. $\widetilde{Q}^h - \widetilde{Q}^p_{sa}$ is decreasing in c as $\frac{d(\widetilde{Q}^h-\widetilde{Q}^p_{sa})}{dc} = b\left(\frac{1}{\sqrt{(1-bk)^2+6bc}} - \frac{2}{\sqrt{(1-bk)^2-30bc}}\right) < 0$ for $c < \frac{(1-bk)^2}{30b}$, and given by $\frac{(\sqrt{30}-3)(1-bk)}{15} > 0$ at $c = \frac{(1-bk)^2}{30b}$. Therefore, $\widetilde{Q}^h - \widetilde{Q}^p_{sa} > 0$ for all $c < C_1(k)$. $\widetilde{\Omega}^p_{sa} - \widetilde{\Omega}^h$ is decreasing in c as $\frac{d(\widetilde{\Omega}^p_{sa}-\widetilde{\Omega}^h)}{dc} = \frac{2b(-1+bk+4\sqrt{(1-bk)^2-30bc)}}{15\sqrt{(1-bk)^2-30bc}} + \frac{b(-1+bk)}{3\sqrt{(1-bk)^2+6bc}} - \frac{b}{3} < 0$, and given by $\frac{(57-10\sqrt{30})(1-bk)^2}{450} > 0$ at $c = \frac{(1-bk)^2}{30}$. Therefore, $\widetilde{\Omega}^p_{sa} - \widetilde{\Omega}^h > 0$ for all $c < C_1(k)$, proving Proposition 1.

To prove Corollary 1, let $E^h = \eta_m \widetilde{Q}^h + \eta_u \widetilde{\Omega}^h$, $E^p_{sa} = \eta_m \widetilde{Q}^p_{sa} + \eta_u \widetilde{\Omega}^p_{sa}$, and $z_2(\omega) = \frac{E^p_{sa}-E^h}{\eta_m+\eta_u} = \omega\left(\widetilde{Q}^p_{sa}(e) - \widetilde{Q}^h(e)\right) + (1-\omega)\left(\widetilde{\Omega}^p_{sa}(e) - \widetilde{\Omega}^h(e)\right)$, where $\omega \doteq \frac{\eta_m}{\eta_m+\eta_u} \in [0,1]$. $z_2'(\omega) = \left(\widetilde{Q}^p_{sa}(e) - \widetilde{Q}^h(e)\right) + \left(\widetilde{\Omega}^h(e) - \widetilde{\Omega}^p_{sa}(e)\right) < 0$, $z_2(0) = \widetilde{\Omega}^p_{sa}(e) - \widetilde{\Omega}^h(e) > 0$, and $z_2(1) = \widetilde{Q}^p_{sa}(e) - \widetilde{Q}^h(e) < 0$ (from Proposition 1). Therefore, there exists a unique value $\omega = \omega_1$ such that $z_2(\omega) = 0$. This implies that if $\omega > \omega_1$, then $E^p_{sa} < E^h$. Otherwise, $E^p_{sa} \geq E^h$.□

Proof of Propositions 2-4 and Corollary 2. We now focus on strong pooling and suppress the notation in the subscript for $\gamma = 2$. Under pure servicizing, the firm's pricing problem is given by $\max_{f^p_{se}} \Pi^p_{se}(f^p_{se}; e) = f^p_{se}\Omega^p_{se}(f^p_{se}; e) - cQ^p_{se}(f^p_{se}; e)$, where $\Omega^p_{se}(f^p_{se}; e) = Q^p_{se}(f^p_{se}; e) = \frac{\left(n^p_{se}\right)^2}{2} = \frac{(1-bf^p_{se}-bk)^2}{2}$, which is positive only if $b(f^p_{se} + k) < 1$. Therefore, for positive profit, we require $c < f^p_{se} < \frac{1-bk}{b}$, which holds if and only if $b(c + k) < 1$. There is a unique solution to the first-order condition given by $f^p_{se} = F^B = \frac{1+2bc-bk}{3b} \in [c, \frac{1-bk}{b}]$. $\Pi^p_{se}(F^B) > 0$ and $\Pi^{p''}_{se}(F^B; e) = -b(1-$

$bc - bk) < 0$. Therefore, F^B is the unique maximizer, and let $f_{se}^{p^*}(e) \doteq F^B$. At the optimal price, $\widetilde{Q}_{se}^p(e) \doteq Q_{se}^p(f_{se}^{p^*}; e) = \frac{2(1-bc-bk)^2}{9}$, $\widetilde{\Omega}_{se}^p(e) \doteq \Omega_{se}^p(f_{se}^{p^*}; e) = \frac{2(1-bc-bk)^2}{9}$, $\widetilde{n}_{se}^p(e) \doteq n_{se}^p(f_{se}^{p^*}; e) = \frac{2(1-bc-bk)}{3}$, and $\widetilde{\Pi}_{se}^p(e) = \frac{2(1-bc-bk)^3}{27b}$.

Under the hybrid business model, the firm's pricing problem is $\max_{f_{sa}^h, f_{se}^h} \Pi^h(f_{sa}^h, f_{se}^h; e) = (f_{sa}^h - c)Q_{sa}^h(f_{sa}^h, f_{se}^h; e) + f_{se}^h \Omega_{se}^h(f_{sa}^h, f_{se}^h; e) - cQ_{se}^h(f_{sa}^h, f_{se}^h; e)$, where $\Omega_{se}^h(f_{sa}^h, f_{se}^h; e) = \frac{(2f_{sa}^h - b{f_{se}^h}^2)^2}{8{f_{se}^h}^2}$, $Q_{se}^h(f_{sa}^h, f_{se}^h; e) = \frac{(n_{se}^h(f_{sa}^h, f_{se}^h, e))^2}{2}$, $n_{se}^h(f_{sa}^h, f_{se}^h; e) = \frac{2f_{sa}^h - b{f_{se}^h}^2}{2f_{se}^h}$, and $n_{sa}^h(f_{sa}^h, f_{se}^h; e) = \frac{f_{se}^h(2-2bk-bf_{se}^h)-2f_{sa}^h}{2f_{se}^h}$. The solution to the first-order conditions yields only one potential local maximizer that satisfies the conditions for $n_{se}^h(f_{sa}^h, f_{se}^h; e), n_{sa}^h(f_{sa}^h, f_{se}^h; e) > 0$, given by $f_{sa}^{h^*}(e) = \frac{\left(-118(bc)^2+3(1-bk)\left(1-bk+\sqrt{24(bc)^2+bc(6-16bk)+(1-bk)^2}\right)+bc\left(-17+24\sqrt{24(bc)^2+bc(6-16bk)+(1-bk)^2}+52bk\right)\right)}{25b}$ and $f_{se}^{h^*}(e) = \frac{\left(1-2bc-bk+\sqrt{24(bc)^2+(1-bk)^2+bc(6-16bk)}\right)}{5b}$, which is a maximizer if and only if $c < C_2(k) \doteq \frac{3\sqrt{1+8(bk)^2}-1-8bk}{8b}$. $n_{sa}^h(f_{sa}^{h^*}, f_{se}^{h^*}; e), n_{se}^h(f_{sa}^{h^*}, f_{se}^{h^*}; e) > 0$ if and only if $c < C_2(k)$. Therefore, under this condition, it is the unique maximizer. At the optimal prices, we have $\widetilde{n}_{sa}^h(e) \doteq n_{sa}^h(f_{sa}^{h^*}, f_{se}^{h^*}; e) = \frac{\left(3\sqrt{(1-bk)^2+24(bc)^2+bc(6-16bk)}-2(1-bk)-16bc\right)}{5}$ (where $\widetilde{Q}_{sa}^h = \widetilde{n}_{sa}^h$) and $\widetilde{n}_{se}^h(e) \doteq n_{se}^h(f_{sa}^{h^*}, f_{se}^{h^*}; e) = \frac{2\left(3(1-bk)+9bc-2\sqrt{(1-bk)^2+24(bc)^2+bc(6-16bk)}\right)}{5}$. Let $\widetilde{\Omega}_{se}^h(e) \doteq \Omega_{se}^h(f_{sa}^{h^*}, f_{se}^{h^*}; e)$, $\widetilde{\Omega}_{sa}^h(e) \doteq \Omega_{sa}^h(f_{sa}^{h^*}, f_{se}^{h^*}; e)$, $\widetilde{Q}_{se}^h(e) \doteq Q_{se}^h(f_{sa}^{h^*}, f_{se}^{h^*}; e)$, and $\widetilde{\Pi}^h(e) \doteq \Pi^h(f_{sa}^{h^*}, f_{se}^{h^*}; e)$ (expressions not provided for brevity). The total adoption and aggregate usage are given by $\widetilde{n}^h \doteq \widetilde{n}_{sa}^h(e) + \widetilde{n}_{se}^h(e) = \frac{\left(4(1-bk)+2bc-\sqrt{(1-bk)^2+bc(6-16bk)+24(bc)^2}\right)}{5}$ and $\widetilde{\Omega}^h \doteq \widetilde{\Omega}_{sa}^h(e) + \widetilde{\Omega}_{se}^h(e) = \frac{236(bc)^2-(1-bk)\left(-19(1-bk)+6\sqrt{24(bc)^2+bc(6-16bk)+(1-bk)^2}\right)-2bc\left(-17+52bk+24\sqrt{24(bc)^2+bc(6-16bk)+(1-bk)^2}\right)}{50}$.

We now examine the firm's optimal choice of business model under strong pooling. Recall that the hybrid business model is valid (i.e., $\widetilde{n}_{sa}^h, \widetilde{n}_{se}^h > 0$) only if $c < C_2(k)$ $(< \frac{(1-bk)^2}{2b})$. The pure servicizing model and pure sales model lead to strictly positive profit only if $c < \frac{1-bk}{b}$, and $c < \frac{(1-bk)^2}{2b}$, respectively. We first begin by comparing the profit between the hybrid and pure sales models. $\widetilde{\Pi}^h - \widetilde{\Pi}_{sa}^p$ is increasing in c because $\frac{d(\widetilde{\Pi}^h - \widetilde{\Pi}_{sa}^p)}{dc} > 0$ (expression not provided for brevity) for $c < C_2(k)$, and given by $\frac{4(1-bk)^3}{675} > 0$ at $c = 0$. This implies that $\widetilde{\Pi}^h > \widetilde{\Pi}_{sa}^p$ for $c < C_2(k)$. Similarly, $\widetilde{\Pi}^h - \widetilde{\Pi}_{se}^p$ is decreasing in c for $c < C_2(k)$ and positive at $c = C_2(k)$. Therefore, $\widetilde{\Pi}^h > \widetilde{\Pi}_{se}^p$ for $c < C_2(k)$. Finally, we compare the pure sales and pure servicizing models for $c \in [C_2(k), \frac{(1-bk)^2}{2b}]$. $\widetilde{\Pi}_{se}^p - \widetilde{\Pi}_{sa}^p$ is strictly concave in c because $\frac{d^2(\widetilde{\Pi}_{se}^p - \widetilde{\Pi}_{sa}^p)}{dc^2} = \frac{4b(1-b(c+k))}{9} - \frac{1}{\sqrt{(1-bk)^2+6bc}} < 0$ for $c \in [C_2(k), \frac{(1-bk)^2}{2b}]$, positive at $c = C_2(k)$ and $c = \frac{(1-bk)^2}{2b}$. This implies that $\widetilde{\Pi}_{se}^p > \widetilde{\Pi}_{sa}^p$ for $c \in [C_2(k), \frac{(1-bk)^2}{2b}]$. Finally, at $c = C_2(k)$, we have that $\widetilde{\Pi}_1^h < 0 < \widetilde{\Pi}_{sa}^p$ as $\frac{(1-bk)^2}{30b} < C_2(k) < \frac{(1-bk)^2}{2b}$. Because $\widetilde{\Pi}_1^h < \widetilde{\Pi}_{sa}^p$ if and only if $c > C_1(k)$, we have that $C_1(k) < C_2(k)$. This proves Proposition 2.

We next compare the hybrid and pure servicizing business models with the pure sales model. First, we focus on the case where the hybrid business model is more profitable, i.e., $c < C_2(k)$. $\widetilde{n}_{sa}^p - \widetilde{n}^h$ is decreasing in c because $\frac{d(\widetilde{n}_{sa}^p - \widetilde{n}^h)}{dc} < 0$ (expression not provided for brevity) for $c < C_2(k)$, and given by $\frac{-4(1-bk)}{15} < 0$ at $c = 0$. Therefore, $\widetilde{n}_{sa}^p < \widetilde{n}^h$ for $c < C_2(k)$. To compare the quantity of products, $\widetilde{Q}^p_{sa} - \widetilde{Q}^h \neq 0$ for $c < C_2(k)$ (i.e., do not intersect) and given by $\frac{2(1-bk)(2+3bk)}{75} > 0$ at $c = 0$. Therefore, $\widetilde{Q}^p_{sa} > \widetilde{Q}^h$ for all $c < C_2(k)$. Finally, $\widetilde{\Omega}^p_{sa} - \widetilde{\Omega}^h \neq 0$ for $c < C_2(k)$ (i.e., do not intersect) and given by $\frac{4(1-bk)^2}{225} > 0$ at $c = 0$. Therefore, $\widetilde{\Omega}^p_{sa} > \widetilde{\Omega}^h$ for all $c < C_2(k)$. This proves Proposition 3.

Next, we focus on the case where the pure servicizing business model is more profitable, i.e., $c \geq C_2(k)$. Note that $\widetilde{n}^p_{sa} > \widetilde{n}^p_{se}$ for all $c \in \big[C_2(k), \frac{(1-bk)^2}{2b}\big)$. To compare the aggregate usage, let $z_3(c) \doteq \widetilde{\Omega}^p_{sa}(e) - \widetilde{\Omega}^p_{se}(e) = \frac{-4(bc)^2 + bc(2-8bk) + 3(1-bk)^2 - 2(1-bk)\sqrt{(1-bk)^2+6bc}}{18}$, which decreases in c. In addition, $z_3\big(C_2(k)\big) > 0$ and $z_3\big(\frac{(1-bk)^2}{2b}\big) = \frac{-(1-bk^2)^2}{18} < 0$ for all $k \in [0,1]$. Therefore, there exists a unique value $c = C_3(k)$, such that $z_3'(c) = 0$, where $C_3(k) > 0$. If $c \leq C_3(k)$, then $z_3(c) \geq 0$ and $\widetilde{\Omega}^p_{sa}(e) \geq \widetilde{\Omega}^p_{se}(e)$. Otherwise, $\widetilde{\Omega}^p_{sa}(e) < \widetilde{\Omega}^p_{se}(e)$. Note that $\widetilde{Q}^p_{sa} - \widetilde{Q}^p_{se}$ is decreasing in c as $\frac{d(\widetilde{Q}^p_{sa} - \widetilde{Q}^p_{se})}{dc} = \frac{b\left(-3+2\sqrt{(1-bk)^2+6bc}\right)}{3\sqrt{(1-bk)^2+6bc}} < 0$ for $c < \frac{(1-bk)^2}{2b}$, it is positive at $c = 0$ and negative at $c = \frac{(1-bk)^2}{2b}$. This implies that there exists a threshold $c = C_4(k)$ obtained by solving $\widetilde{Q}^p_{sa} = \widetilde{Q}^p_{se}$, such that if $c < C_4(k)$, then $\widetilde{Q}^p_{sa} > \widetilde{Q}^p_{se}$, otherwise $\widetilde{Q}^p_{sa} \leq \widetilde{Q}^p_{se}$, where $C_4(k) < \frac{(1-bk)^2}{2b}$ for all $k < 1$. Finally, as $\widetilde{Q}^p_{sa} > \widetilde{Q}^p_{se}$ for $c < C_3(k)$, we have that $C_3(k) < C_4(k)$. This proves Proposition 4.

To prove Corollary 2, let $E^h = \eta_m \widetilde{Q}^h + \eta_u \widetilde{\Omega}^h$, $E^p_{se} = \eta_m \widetilde{Q}^p_{se} + \eta_u \widetilde{\Omega}^p_{se}$, and $E^p_{sa} = \eta_m \widetilde{Q}^p_{sa} + \eta_u \widetilde{\Omega}^p_{sa}$. First, we focus on the case where the hybrid servicizing model is more profitable, i.e., $c < C_2(k)$. To compare its environmental impact with that under pure sales model, note that $E^p_{sa} - E^h = \eta_m(\widetilde{Q}^p_{sa} - \widetilde{Q}^h) + \eta_u(\widetilde{\Omega}^p_{sa} - \widetilde{\Omega}^h) > 0$ because $\widetilde{Q}^p_{sa} > \widetilde{Q}^h$ and $\widetilde{\Omega}^p_{sa} > \widetilde{\Omega}^h$ (from Proposition 3). Therefore, if $c < C_2(k)$, then $E^p_{sa} > E^h$. Next, we focus on the case where the pure servicizing model is more profitable, i.e., $c \geq C_2(k)$. Let $z_4(\omega) = \frac{E^p_{sa} - E^p_{se}}{\eta_m + \eta_u} = \omega\left(\widetilde{Q}^p_{sa}(e) - \widetilde{Q}^p_{se}(e)\right) + (1-\omega)\left(\widetilde{\Omega}^p_{sa}(e) - \widetilde{\Omega}^p_{se}(e)\right)$, where $\omega \doteq \frac{\eta_m}{\eta_m + \eta_u}$. If $c \in \big[C_2(k), C_3(k)\big)$, then as above we have that $E^p_{sa} > E^p_{se}$ because $\widetilde{Q}^p_{sa}(e) > \widetilde{Q}^p_{se}(e)$ and $\widetilde{\Omega}^p_{sa}(e) > \widetilde{\Omega}^p_{se}(e)$ (from Proposition 4). If $c \in [C_3(k), C_4(k)]$, then we have that $z_4'(\omega) = \left(\widetilde{Q}^p_{sa}(e) - \widetilde{Q}^p_{se}(e)\right) + \left(\widetilde{\Omega}^p_{se}(e) - \widetilde{\Omega}^p_{sa}(e)\right) > 0$, $z_4(0) = \widetilde{\Omega}^p_{sa}(e) - \widetilde{\Omega}^p_{se}(e) < 0$, and $z_4(1) = \widetilde{Q}^p_{sa}(e) - \widetilde{Q}^p_{se}(e) > 0$, because $\widetilde{\Omega}^p_{se}(e) > \widetilde{\Omega}^p_{sa}(e)$ and $\widetilde{Q}^p_{sa}(e) > \widetilde{Q}^h(e)$ (from Proposition 4). Therefore, there exists a unique value $\omega = \omega_2$ such that $z_4(\omega) = 0$. This implies that if $\omega < \omega_2$, then $E^p_{sa} < E^p_{se}$, otherwise $E^p_{sa} \geq E^p_{se}$. Finally, if $c \in \big[C_4(k), \frac{(1-bk)^2}{2b}\big]$, then we have $E^p_{sa} < E^p_{se}$ because $\widetilde{Q}^p_{sa}(e) < \widetilde{Q}^p_{se}(e)$ and $\widetilde{\Omega}^p_{sa}(e) < \widetilde{\Omega}^p_{se}(e)$ (from Proposition 4).□

Proof of Proposition 5.A customer's usage under the sales option is $q^{i^*}_{sa}(\theta; f^{i^*}_{sa}, e) = \theta - bk(e)$, for $i \in \{p, h\}$, which is increasing in e as $k(e)$ is decreasing in e. We first focus on servicizing under no pooling ($\gamma = 1$). For pure servicizing, $\frac{dq^{p^*}_{se}(\theta; f^{p^*}_{se}, e)}{de} < 0$ only if $c_0 > \widehat{C}^p_1(k_0) \doteq \frac{2k_0(1-bk_0) + bek_0^2}{6e}$. Moreover, $\frac{dq^{i^*}_{sa}(\theta; f^{i^*}_{sa}, e)}{de} - \frac{dq^{p^*}_{se}(\theta; f^{p^*}_{se}, e)}{de} = \frac{6bc_0e + bk_0(-1+bk_0(1-e)) + 2bk_0\sqrt{(1-bk_0(1-e))^2 - 6bc_0e^2}}{3\sqrt{(1-bk_0(1-e))^2 - 6bc_0e^2}}$ which is positive. For the hybrid model, $\frac{dq^{h^*}_{se}(\theta; f^{h^*}_{se}, e)}{de} = bk_0 + \frac{2}{15}\big(-4bk_0 + \frac{-30bc_0e + bk_0 - (1-e)bk_0^2}{\sqrt{-30bc_0e^2 + (1-bk_0(1-e))^2}}\big)$, which is negative only if $c_0 > \widehat{C}^h_1(k_0)$ (expression not provided for brevity). Moreover, $\frac{dq^{i^*}_{sa}(\theta; f^{i^*}_{sa}, e)}{de} - \frac{dq^{p^*}_{se}(\theta; f^{p^*}_{se}, e)}{de} = \frac{2}{15}\big(4bk_0 + \frac{30bc_0e - bk_0 + (1-e)(bk_0)^2}{\sqrt{-30bc_0e^2 + (1-bk_0(1-e))^2}}\big)$, which is always positive for $c(e) < C_1\big(k(e)\big)$.

We now focus on servicizing with strong pooling ($\gamma = 2$). For pure servicizing, $\frac{dq_{se}^{p^*}(\theta;f_{se}^{p^*},e)}{de} = \frac{2b(k_0-2c_0e)}{3}$, which is negative if and only if $c_0 > \widehat{C}_2^p(k_0) \doteq \frac{k_0}{2e}$. Moreover, $\frac{dq_{sa}^{i^*}(\theta;f_{sa}^{i^*},e)}{de} - \frac{dq_{se}^{p^*}(\theta;f_{se}^{p^*},e)}{de} = \frac{b(4c_0e+k_0)}{3} > 0$. For the hybrid model, $\frac{dq_{se}^{h^*}(\theta;f_{se}^{h^*},e)}{de} = \frac{b}{5}\big(4(c_0e + k_0) + \frac{6c_0e(1+8bc_0e^2)+k_0+8bc_0ek_0(-2+3e)-bk_0^2(1-e)}{\sqrt{24(bc_0)^2e^4+(1-bk_0(1-e))^2+2bc_0e^2(3-8bk_0(1-e))}}\big)$, which is negative if $c_0 > \widehat{C}_2^h(k_0)$ (expression not provided for brevity). Moreover, $\frac{dq_{sa}^{i^*}(\theta;f_{sa}^{i^*},e)}{de} - \frac{dq_{se}^{h^*}(\theta;f_{se}^{h^*},e)}{de} = \frac{b}{5}\big(- 4c_0e + k_0 + \frac{6c_0e(1+8bc_0e^2)+k_0+8bc_0ek_0(-2+3e)-bk_0^2(1-e)}{\sqrt{24b^2c_0^2e^4+(1-bk_0(1-e))^2+2bc_0e^2(3-8bk_0(1-e))}}\big)$, which can be shown to be positive for $c(e) < C_2\big(k(e)\big)$.□

Proof of Proposition 6. Let $b = 1$. We first solve for the optimal efficiency under our benchmark case of the pure sales model. We assume $c_0 < 1/2$ to ensure that the firm has positive profit for all $e \in [0,1]$. The firm's problem is given by $\max_{0 \le e_{sa}^p \le 1} \widetilde{\Pi}_{sa}^{p^*}(e_{sa}^p)$. If $c_0 < \frac{k_0(2+k_0)}{6}$, then $\widetilde{\Pi}_{sa}^{p^*}(e_{sa}^p)$ increases in e_{sa}^p for $0 \le e_{sa}^p \le 1$, which implies that $e_{sa}^{p^*} = 1$. If $\frac{k_0(2+k_0)}{6} \le c_0 < \frac{1}{2}$, $\widetilde{\Pi}_{sa}^{p^*}(e_{sa}^p)$ increases in e_{sa}^p for $e_{sa}^p \in \left[0, \frac{2k_0(2-k_0)}{3(2c_0-k_0^2)}\right)$ and decreases in e_{sa}^p for $e_{sa}^p \in \left[\frac{2k_0(2-k_0)}{3(2c_0-k_0^2)}, 1\right]$, and consequently $e_{sa}^{p^*} = \frac{2k_0(2-k_0)}{3(2c_0-k_0^2)}$. In sum, if $c_0 < \frac{k_0(2+k_0)}{6}$, then $e_{sa}^{p^*} = 1$. Otherwise, $e_{sa}^{p^*} = \frac{2k_0(2-k_0)}{3(2c_0-k_0^2)}$.

We now solve the firm's optimal efficiency choice, when it is optimal to offer a servicizing business model. We first focus on the case with no pooling. Recall that the firm either offers a hybrid business model or a pure sales model. In order to avoid the uninteresting comparison when the firm prefers to offer a pure sales model, we assume $k_0 < K_1(c_0) \doteq 1 - \sqrt{30c}$, which ensures that the firm prefers to offer a hybrid business model for all $e \in [0,1]$, i.e., the condition $c(e) < C_1\big(k(e)\big)$ holds for all $e \in [0,1]$. The firm's problem is then given by $\max_{0 \le e_1 \le 1} \widetilde{\Pi}_1^*(e) = \widetilde{\Pi}_1^{h^*}(e)$. If $c_0 \le C_{5\gamma=1}(k_0)$, then $\widetilde{\Pi}_1^{h^*}(e_1)$ increases in e_1 for all $0 \le e_1 \le 1$, which implies that $e_1^* = 1$. Otherwise, $\widetilde{\Pi}_1^{h^*}(e_1)$ increases in e_1 for $e_1 \in [0, e_x]$ and decreases thereafter, and consequently, $e_1^* = e_x$ (expression not provided for brevity). Therefore, $e_1^* = 1$ if $c_0 \le C_{5\gamma=1}(k_0)$, and $e_1^* = e_x$ otherwise. We next compare e_1^* with $e_{sa}^{p^*}$. Under $k_0 < K_1(c_0)$, we have $C_{5\gamma=1}(k_0) < \frac{k_0(2+k_0)}{6}$. If $c_0 < \frac{k_0(2+k_0)}{6}$, then $e_{sa}^{p^*} = 1$ and $e_1^* \le 1$, which implies $e_{sa1}^{p^*} \ge e_1^*$. If $c_0 > \frac{k_0(2+k_0)}{6}$, then $e_{sa}^{p^*}, e_1^* < 1$. Under these conditions, we have $e_1^* < e_{sa}^{p^*}$.

We next focus on the case with strong pooling. Recall that for $c(e) < C_2\big(k(e)\big)$, the firm offers a hybrid servicizing model, and otherwise, offers a pure servicizing model, i.e., $\widetilde{\Pi}_2^*(e) = \widetilde{\Pi}_2^{h^*}$ if $c(e) < C_2(k(e))$, and $\widetilde{\Pi}_2^*(e) = \widetilde{\Pi}_{se2}^{p^*}$ otherwise. For this proof, we assume $k < K_2 = 1/2$ for analytical tractability and brevity. Under this condition, there exists a threshold $e = e_y$ such that the condition $c(e) < C_2\big(k(e)\big)$ can be written as $e < e_y$. In addition, $\widetilde{\Pi}_2^*(e)$ is continuous and continuously differentiable at $e = e_y$. Moreover, we have that if $c_0 \le \frac{k_0}{2}$, then $\widetilde{\Pi}_{se2}^{p^*}(e)$ increases in e for all $e \in [0,1]$. Otherwise, $\widetilde{\Pi}_{se2}^{p^*}(e)$ increases in e for $e \in \left[0, \frac{k_0}{2c_0}\right]$ and decreases thereafter. Similarly, if $c_0 \le C_{5\gamma=2}(k_0)$, then $\widetilde{\Pi}_2^{h^*}(e)$ increases in e for all $e \in [0,1]$. Otherwise, there exists a threshold $e = e_z$ such that it increases in e for $e \in [0, e_z]$ and decreases thereafter. In addition, it can be shown that $\frac{2k_0(2-k_0)}{3(2c_0-k_0^2)} < C_{5\gamma=2}(k_0) < \frac{k}{2}$. If $c_0 < C_{5\gamma=2}(k_0)$, then $\widetilde{\Pi}_2^*(e)$ is increasing in e for all $e \in [0,1]$, and $e_2^* = 1$. Since $e_{sa}^{p^*} \le 1$ under this condition, we have $e_2^* \ge e_{sa}^{p^*}$. If $C_{5\gamma=2}(k_0) < c_0$, then $e_{sa}^{p^*} < 1$, and there are three possible candidates to be the global maximizer for $\widetilde{\Pi}_2^*(e)$, viz., e_z, $\frac{k_0}{2c_0}$ or 1. However, we have that $\frac{d\widetilde{\Pi}_2^{h^*}}{de}(e^p_{sa}) < 0$ and $\frac{d\widetilde{\Pi}_{se2}^{p^*}}{de}(e^p_{sa}) < 0$, which implies that $e^{p^*}_{sa} < e_z, \frac{k_0}{2c_0}, 1$ or $e^{p^*}_{sa} < e_2^*$. □

A2. Calibration of the model parameters

In what follows, we provide a detailed description of the methods and sources we used to calibrate our model with the real-life estimates discussed in §4.1. We consider two different examples to capture the extremes of pooling efficacy: document management services where $\gamma = 1$ and cloud services where $\gamma = 2$. For each of them, we estimate the following three parameters: i) the maximum value for customers' usage needs Θ (which is normalized to 1 in our model), ii) the operating cost k, and iii) the unit production cost c.

Document management services. We first calculate the maximum value for customers' usage needs Θ in pages/day using the data for Xerox's document management services found in Ning et al. (2014): The mean monthly print volume is $\mu = 2,699$ pages with a standard deviation of $\sigma = 3,504$. We calculate Θ as $\mu + 2 \times \sigma$, which gives 10,000 pages/month, or $\Theta = 10,000/30 = 333.333$ pages/day (assuming 30 days in a month). To calculate the production cost for a printer we utilize information from Xerox's financial statement and average market prices for office-use printers. In particular, the profit margin for Xerox's Document Technology division is 10% (Xerox 2013b). To estimate the market price, we focus on Xerox's Color Multifunction printers which vary from $\{\$6.6 \times 10^3, \$8.8 \times 10^3, \$11 \times 10^3, \$13.2 \times 10^3\}$ for different models (Xerox 2015a). The production cost can then by obtained by multiplying these values by $(1 - 0.1)$, which gives $c \in \{\$6 \times 10^3, \$8 \times 10^3, \$10 \times 10^3, \$12 \times 10^3\}$.

In order to calculate the operating cost k, we need to estimate the cost of ink/toner and cost of electricity in terms of \$/page. From Xerox (2015b), we estimate the average cost of toner/ink to be \$0.1/page (business proposal category). A Xerox Color Multifunction printer consumes 402 watts when running and 111 watts in a standby mode (Xerox 2015a). The specific printer can print up to 20 pages/minute, which means that a monthly volume of 10,000 pages implies 500 minutes of "continuous" printing per-month. Therefore, we calculate the maximum possible electricity consumption as $\frac{400 \text{ watts} \times \frac{500}{60} \frac{\text{hours}}{\text{month}} + 111 \text{ watts} \times \left(24 \times 30 - \frac{500}{60}\right) \frac{\text{hours}}{\text{month}}}{1{,}000} = 82.345$ kWh/month (assuming 24 hours in a day and 30 days in a month). Since, our customers are uniformly distributed we use the average monthly print volume $10,000/2 = 5,000$ to calculate $82.345/5,000 = 0.0165$ kWh/page as our average electricity consumption. We then multiply 0.0165 kWh by 0.0956 \$/kWh, which was the average electricity price for commercial customers in the South Atlantic region of the US during January 2015 (U.S. Energy Information Administration 2015), and obtain the electricity cost as \$0.00157/page. Therefore, the operating cost is $0.1 + 0.00157 = \$0.10157$/page.

As our model parameters are between zero and one, we need to normalize our estimates. We do this by dividing the estimates of the production and operating costs by $\Theta = 333.333$ pages/day, which is normalized to one in our model. In addition, given that the production cost is incurred only once over the product's entire useful life, we divide c by 1460 days (or 4 years), which is the average useful life of a printer (Statista 2015). This normalization yields the following estimates for our parameters: $c \in \{0.0123, 0.0164, 0.0205, 0.0247\}$ and $k = 0.0003$ per page. As there is a lack of estimates regarding the change in printing per unit change in operating cost, we use $b = 1$.

Cloud services. We first calculate the maximum value for customers' storage needs by considering the plans offered by different cloud storage providers such as SugarSync, Dropbox, Google Drive, Box, etc. There is significant diversity in the available plans, however, SugarSync is one that has several different storage tiers: 100GB, 250GB, 500GB, and 1TB, out of which the 250GB is the most popular (see SugarSync 2015). Based on this, we choose $\Theta = 400$GB as our estimate of customers' maximum storage needs. To calculate the production cost for a server we utilize information from IBM's financial statement and average market prices for IBM servers. The profit margin for IBM's Systems and Technology division is 35.6% (IBM 2013b). As servers come in a variety of configurations and capacities, we choose a range of prices given by $\{\$3 \times 10^3, \$6 \times 10^3, \$9 \times 10^3, \$12 \times 10^3\}$. Accordingly, the production cost can be obtained by multiplying these values by $(1 - 0.395)$, which gives approximately $\{\$2 \times 10^3, \$4 \times 10^3, \$6 \times 10^3, \$8 \times 10^3\}$.

With respect to the operating cost k, we find an average annual cost of storage of approximately \$0.23 per GB from Diogenes Labs (2008) and \$0.186 per GB from Oracle (2015) (for the EMC Isilon Single-copy disk solution with 3,262TB usable disk capacity). Therefore, we assume an annual operating cost of \$0.2 per GB which translates to approximately a monthly cost of \$0.02 per GB. As before, we normalize our estimates by dividing them by $\Theta = 400$GB. In addition, we also divide the production cost estimate by 48 months (or 4 years), which is the average useful life of a server (see Dell 2012). This yields the following estimates for our parameters: $c \in \{0.112, 0.205, 0.299, 0.392\}$ and $k = 4.79 \times 10^{-5}$ per GB. Finally, as there is a lack of information regarding estimates of the change in storage use per unit change in operating cost, b, we use $b = 1$.

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