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Can direct finance within a servitizing supply chain reduce the moral hazard associated with the servitized user's care of the product?

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Abstract
Servitizing business models can provide economic benefits in a supply chain by utilizing products more efficiently. However, the transfer of the burden to keep the product operable from the user to the servitizing provider may cause issues. As a result of no longer *owning* the product, a user may be less inclined to taking care of it thereby increasing the maintenance effort for the servitizing provider. This may induce additional financial stress on the latter, specifically if it is a small company with lack of budget to begin with. In this study we analyze whether direct finance within a supply chain, where the user lends money to the servitizing provider, can alleviate this problem, when compared with a more traditional bank finance option. We find that improved access to finance indeed enables the servitizing provider to induce high effort by the user through lower servitizing fees. This also makes the servitizing model economically more attractive for both firms involved. Besides those economic implications, direct finance increases consumer demand and surplus, while at the same time resource consumption for satisfying this increased demand increases.

Keywords Servitization · Maintenance cost · Financially constrained firm · Supply chain finance · User effort

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1 Introduction

Over the last decade, various industries have been characterized by firms implementing a business model termed 'servicizing' (Toffel 2008). The innovative feature is that the firms sell the functionality or use of the product rather than the product itself. This may provide a win-win situation for users and servitizing providers. One of the key benefits for firms typically attributed to servicizing is the potential to use resources more efficiently through pooling (Agrawal and Bellos 2017). For the servitized users, the large upfront investment (the purchase price) is eliminated, and they face lower financial risk as the responsibility of maintaining the functionality of the product lies with the servitizing provider. For example, Rolls Royce servitizes the engines to airline firms. Rolls Royce retains the ownership of the engines and maintains the engine, the airline firms only pay for the function of the product (Örsdemir et al. 2019).

However, for the servitizing provider, maintenance cost plays an important role as it impacts the profitability of the business model. Baveja et al. (2004) state that only 21% of firms succeeded with their servitizing strategy. Neely (2008) show empirically that servitization businesses are less profitable than pure sales businesses due to higher costs for the servitizing provider. Interface's servitization program failed due to high cost (Olivia and Quinn 2003). In the academic literature this has led to the formulation of the servitization paradox–even though servitization creates opportunity for the servitizing provider to increase the revenue, it does not always produce the anticipated profit (Gebauer et al. 2005; Neely 2008; Ulaga and Loveland 2014).

The maintenance cost can be largely affected by the level of effort that users exert in taking good care of the product. The level of the effort can manifest in a few ways. For example, the users can provide good staff training, or keep a good environment for placing the device (proper temperature and so on). While effort is costly, it may also reduce the operating cost observed by users. However, Bardhi and Eckhardt (2012) point out, that users have less incentive to look after the product when they do not own the product. Indeed, a servitizing provider may face high maintenance costs and the risk of bankruptcy if users show low effort to carefully use the product under the servitization strategy. This kind of moral hazard has been mentioned in some recent research (Hezarkhani et al. 2022; Örsdemir et al. 2019; Goering 1997, 2008; Jiang et al. 2021). Yet, to our best knowledge it remains an open question as to how to reduce or even eliminate this moral hazard.

Different supply chain financing strategies have been studied for resolving moral hazard problems and aligning incentives along a supply chain in general. Babich and Tang (2012) state that deferred payments can be a way to solve moral hazard of selling adulterated products. Rui and Lai (2015) study the combination of delayed payments and inspection policies to control the risk of suppliers using low quality inputs. Tang et al. (2018) examine if buyer direct finance can solve supplier's moral hazard of not delivering products on time. Devalkar and Krishnan (2019) investigate if trade credit can solve supplier's moral hazard when considering working capital

financing cost. In all of these papers, the financing firm aims at reducing or eliminating the moral hazard of the other firm directly.

In this study, we investigate if supply chain financing can solve the moral hazard of careless product use under servitization. Specifically, we consider bank finance as a benchmark and user-direct finance, as in our setting the user is the *buyer* of the service. Our focus on user-direct finance stems from the below reasons. First, servitizing providers are most likely to be capital-constrained as they charge fees based on the usage time rather than receiving the upfront payment under the traditional selling business model. It is especially difficult for small to medium-sized enterprises to finance their production from banks due to their poor credit rating and insufficient collateral (Giannetti et al. 2011). Supply chain finance has become a prevailing financing option in such settings lately (Kouvelis and Zhao 2012). For example, GlaxoSmithKline (GSK) has lent billions of pounds to its suppliers (Tang et al. 2018). Amazon has introduced a lending program to finance its small sellers (Rath et al. 2021). Ford provides loans to its suppliers after the financial downtime in 2008 (Deng et al. 2018). As of the financial year of 2016, the figure for trade credit owed by buyers to their suppliers is 3.3 times as large as the figure for bank loans on the non-financial US businesses aggregated balance sheet (Yang and Birge 2018).

Under bank finance the servitizing provider borrows money from a bank for a given interest rate. Conversely, in user-direct finance the user—by setting the interest rate—can incentivize a particular behavior of the servitizing provider, which in turn can affect her own behavior and thereby directly influence the supply chain performance. Specifically, offering a lower interest rate to the servitizing provider will reduce his effective cost, and may thereby lead to a reduced price charged for servitizing. Facing such a reduced servitizing price may consequently allow the user to also lower the consumer price she charges, thereby stimulating demand. The economies of scale arising from increased demand may, together with reduced unit operating cost due to more careful product usage (Bardhi and Eckhardt 2012), make expending higher effort indeed worthwhile.

Given this distinct difference of the two financing strategies and the above mentioned conjectured behavior we want to answer the following research questions: Does user-direct finance increase the user's effort of looking after the servitized product? Does the servitizing provider prefer user-direct finance over bank finance? When would the user offer direct finance to the servitizing provider instead of letting him borrow from the bank?

To answer these questions, we consider a Stackelberg game between a financially-constrained servitizing provider (he) and a user (she) who uses the product to satisfy consumer demand. Both servitizing provider and user are risk-neutral, expecting to maximize their profits. To focus on the interaction between the financing strategy and the effort exerted by the user we assume that the servitizing provider provides a 100% guaranteed uptime contract to the user. Our analysis shows that user-direct finance can never lead to lower effort exerted by the user when compared with bank finance. Any increase in effort induced by user-direct finance is always preferred by both the servitizing provider and the user, despite its associated cost.

The remainder of the paper is organized as follows. In the next section we review the literature our work builds on and contributes to. After presenting our model in

Sect. 3, we show the results of our analysis in Sect. 4 and an extension model considering continuous effort level in Sect. 5. Our paper ends with a conclusion including managerial implications of our results as well as an outlook on open questions for further research. All mathematical proofs are contained in an appendix for the sake of the readability of the main text.

2 Literature review

Our work is related to and builds on two streams of academic research: servitization as a business strategy, and the role and efficiency of supply chain financing.

The first stream deals with the design of the servitization strategy. Agrawal and Bellos (2017) study the profitability and environmental impact of servitization when considering different pooling efficiency. While pooling reduces unit cost for the servitizing provider, they do not explicitly consider the impact of user behavior on maintenance cost. Örsdemir et al. (2019) assume that maintenance cost may increase due to customer's misuse and study when servitization can increase the profitability and benefit the environment at the same time. They find that use impact and operating efficiency play important roles when servitization becomes a win-win solution. Hezarkhani et al. (2022) examine the optimal contracting of maintenance services and they incorporate the effect of different effort levels of customer's taking care of the product. They show that an optimal servitizing contract can also coordinate the customer's effort. Jiang et al. (2021) examine the financing strategy of a servitizing provider, comparing bank finance with buyer direct finance. In their model, the servitizing fee is exogenously given. Our paper contributes to this stream of research by providing insights into the impact of different supply chain financing strategies on the servitization business model. Further, compared with Jiang et al. (2021), in our model the servitizing price is endogenously set by the servitizing provider.

The second stream considers the efficiency and role of direct finance in supply chain management. Yi et al. (2021) examine the financing strategy of a capital constrained small farmer by comparing bank finance, direct finance and guarantor finance. Direct finance is preferred by the small farmer when his production cost is low and unit commission fee is high, otherwise, the small farmer prefers guarantor financing guaranteed by a platform. Under both direct finance and guarantor finance, the small farmer produces more products than in a centralized system. Deng et al. (2018) compare bank finance and buyer direct finance considering an assembly system with one assembler and multiple small suppliers. They show that buyer finance can increase the profit of the assembler and the efficiency of the whole supply chain. There is an increasing body of literature examining the relationship between moral hazard and supply chain finance (Kouvelis and Zhao 2012; Yang and Birge 2018; Devalkar and Krishnan 2019). Kouvelis and Zhao (2012) and Yang and Birge (2018) establish how supply chain efficiency can be improved as demand risk can be shared under trade credit. Devalkar and Krishnan (2019) examine how trade credit can reduce supplier's moral hazard with considering working capital financing cost. The work that is particularly relevant to

our paper is Tang et al. (2018). In their paper, they compare the impact of bank finance and buyer direct finance on supplier risk. They consider a supply chain consisting of a capital constrained supplier and a manufacturer. The manufacturer offers direct finance to the supplier, and sets a purchase price contingent on the successful delivery of products by the supplier. They show that both bank finance and direct finance produce the same profit for manufacturer and direct finance does not mitigate the supplier's performance risk when there is no information asymmetry. In contrast, in line with most of the servitizing literature (Örsdemir et al. 2019; Agrawal and Bellos 2017; Hezarkhani et al. 2022), we let the manufacturer (servitizing provider) offer a contract indicating the servitizing price, and we focus on the user's effort of looking after the servitized product rather than the supplier's performance risk. We also consider the opportunity cost that the user needs to give up when offering direct financing to the servitizing provider. In that setting, we examine if direct finance can improve the user's effort of taking care of the servitized product.

3 The model

We model a two-echelon supply chain with a servitizing provider servitizing its product to a user who uses the product to satisfy consumer demand. We assume that the user needs to allocate one product to each consumer, and consumers pay p for the service. To focus on the supply chain interaction between the user and the servitizing provider we keep the consumer side simple and consider a linear demand $q = 1 - p$. Besides setting this price p the user also decides on the effort e exerted in using the product. We assume that the user can either exert low effort $e_l = 0$ or high effort $e_h = 1$. The cost of exerting effort is $a * e_i^2$, for $i = l, h$. For providing the service to consumers the user incurs an operating cost to run the product. For example, the airline firm rents the engine but still needs to pay the fuel to fly the airplane. This operating cost is also affected by effort e, as using the product with care can lower the product deterioration rate, e.g. the fuel consumption (Bardhi and Eckhardt 2012). It is given by $(1 - e) * \bar{c}$.[1] In the following let us denote $c_l = \bar{c}$ and $c_h = 0$ the operating cost under low and high effort, respectively. In that setting, $\bar{c}$ is the difference in operating cost between high and low effort. Under the servitizing agreement, the user also pays a periodic fee f per used product to the servitizing provider.

The servitizing provider incurs a per-unit production cost of g for the product as well as the maintenance cost $m(e)$ for ensuring that the product operates properly. Maintenance cost $m(e)$ is affected by the user effort level e. Higher user's effort of taking care of the product can reduce the maintenance cost (Hezarkhani et al. 2022), so the maintenance cost m_e is decreasing in e. For low user effort (e_l), let the servitizing provider's high maintenance cost be denoted by $m_l := m(e_l)$, while for high effort the servitizing provider is faced with low maintenance cost $m_h := m(e_h)$.

[1] Note that this implies that for simplicity and without loss of generality, the operating cost under high effort is normalized to zero.

Table 1 Notation of the model

$i \in \{l, h\}$	.	Index for the level of effort, low (l) or high (h)
$j \in \{b, d\}$	.	Index for the financing scheme, bank (b) or direct (d)
p_{ij}	.	Consumer price for the product in financing scheme j under effort level i
f_{ij}	.	Servitizing price in financing scheme j under effort level i
a	.	Unit cost of effort for the user
g	.	Unit production cost for the servitizing provider
m_i	.	Unit maintenance cost of the servitizing provider under effort level i
c_i	.	Unit operating cost of the user under effort level i
$\bar{c}$	.	Difference in operating cost between high and low effort
r_j	.	Interest rate for borrowing in financing scheme j
r_a	.	Interest rate the user can earn via alternative investment
K	.	Budget of user available for investments
π_{ij}^s	.	Servitizing provider's profit in financing scheme j under effort level i
π_{ij}^u	.	User's profit in financing scheme j under effort level i

In our model, we assume the servitizing provider has the necessary equipment used for production, yet it can not be used as collateral asset. Apart from that the servitizing provider has no cash on hand. He needs to borrow money to cover the production cost g and can do so either from the bank or from the user if the user offers the direct finance option to the servitizing provider. Under bank finance, the servitizing provider borrows the required money to cover his production cost at an exogeneously given interest rate r_b, set by the bank. Conversely, under the direct financing scheme, the bank does not play a direct role. Rather, the interest rate r_d is endogenous and determined by the user. Thus in this setting the user has an additional decision (besides setting consumer price and effort). For this decision she also has to consider the opportunity cost of lending money to the servitizing provider. To model that we consider an exogeneously given interest rate r_a which the user could exploit by an alternative investment. We also assume that the user has the budget K available for investing (in the alternative investment or the financing of the servitizing provider).

Table 1 summarizes the notation used in the remainder of the text.

Before we discuss the implications of the two financing options let us outline the sequence of the events: First, the financially constrained servitizing provider observes the bank interest rate, and – if offered by the user – the terms of the direct finance scheme, i.e. the interest rate set by the user. He then chooses the preferred financing option and offers the servitizing price to the user. Next, the user determines the consumer price and her effort level to service consumer demand. Finally, the servitizing provider repays the principle and the interest to the bank or the user, depending on the financing option utilized.

In that setting, the servitizing provider's decisions are driven by the maximization of the following profit function:

$$\pi_{ij}^s = (f_{ij} - m_i - g - gr_j)(1 - p_{ij}), \quad i \in \{l, h\}, j \in \{b, d\}. \tag{1}$$

In summary, the servitizing provider's profit is the product of the consumer demand $1 - p_{ij}$ and the per-unit revenue, which is given by the servitizing price minus the sum of maintenance and production cost, including the cost of capital driven by the interest rate r_j.

Observe that servitizing price f_{ij} and consumer price p_{ij} are decisions taken by the servitizing provider and the user, respectively. Thus they depend on the financing option in place. Similarly, the interest rate depends on the financing option (as it is a decision variable for the user under direct financing). And finally, maintenance cost depends on the effort exerted, which will of course also depend on the financing option.

As mentioned above, under bank finance the servitizing provider borrows the required money to cover his production cost at an exogeneously given interest rate r_b, set by the bank. In that case, the user's profit as a function of her decisions p and e is simply given by

$$\pi^u_{ib} = (p_{ib} - f_{ib} - c_i)(1 - p_{ib}) - ae_i^2 + Kr_a, \quad i \in \{l, h\}. \tag{2}$$

The buyer's profit is the product of the consumer demand $1 - p_{ib}$ and the per-unit revenue, given by consumer price minus the sum of servitizing price and operating cost, minus the fixed cost of effort, plus the income generated from the budget invested in the alternative investment.

Under the user-direct financing scheme, the profit she tries to maximize by setting the retail price p, effort e and interest rate r_d is given by

$$\pi^u_{id} = (p_{id} - f_{id} - c_i)(1 - p_{id}) - ae_i^2 + Kr_a + g(1 - p_{id})(r_d - r_a), \quad i \in \{l, h\}. \tag{3}$$

Observe that the first three parts are structurally the same as under bank finance, while the fourth term captures the opportunity cost of lending the money to the servitizing provider. Specifically, the amount of money lent $g(1 - p_{id})$ earns an interest r_d and foregoes the interest r_a.

Intuitively, the three interest rates need to satisfy the following conditions. First, $0 \leq r_a \leq r_b$, i.e. the interest the user could get from the alternative investment is non-negative but lower than the bank credit interest rate. Otherwise, the user could exploit arbitrage and simply make an unlimited profit by borrowing from the bank and making the alternative investment. Second, $r_d \geq -1$, which implies that the user could in fact subsidize the servitizing provider up to the entire cost of production; note that this is in line with the related literature (Deng et al. 2018; Kouvelis and Zhao 2012; Jiang et al. 2021).

4 Analysis

To answer our research questions, we solve the model by backward induction. We start our analysis by determining the optimal decisions by both firms under bank finance and user-direct finance, separately. Then we compare the two financing options.

4.1 Optimal decisions of the servitizing provider and the user under bank finance

As mentioned above, we start by characterizing the optimal prices set by the user and the servitizing provider under low and high effort, respectively. Then we analyze the optimal effort choice for the user.

Lemma 1 (User's reaction under bank finance) *Under bank finance the user's optimal consumer price is given by* $p_{ib} = \frac{1+f_{ib}+c_i}{2}$, *with* $i \in \{l, h\}$. *The user chooses high effort* e_h, *iff* $f_{hb} \leq \bar{f}_b$ *where* $\bar{f}_b = 1 - \frac{2a}{\bar{c}} - \frac{\bar{c}}{2}$. *Otherwise she chooses low effort* e_l.

From this lemma we observe that consumer price and effort are linked in two ways. First, consumer price is directly lowered under high effort as the operating cost is reduced. Second, high effort is induced when the servitizing price is sufficiently low, which at the same time leads to a lower consumer price. So when the user exerts high effort she lowers consumer price to stimulate consumer demand.

The next result summarizes the servitizing provider's pricing decision.

Lemma 2 (servitizing provider's pricing decision under bank finance) *Under bank finance the servitizing provider's locally optimal servitizing price is given by* $f^*_{ib} = \frac{1-c_i+(1+r_b)g+m_i}{2}$, *for* $i = h, l$.

In Lemma 1 we found that high effort is chosen when the servitizing price is sufficiently low. The results in Lemma 2 highlight that vice versa, effort may affect the servitizing price positively or negatively, depending on the term $(m_i - c_i)$, $i \in l, h$. When this term increases (decreases) with increasing effort, the optimal servitizing price also increases(decreases). In other words when the effect of increasing effort reduces the servitizing provider's maintenance cost relatively stronger (weaker) than it reduces the user's operating cost, the servitizing price decreases (increases). Put differently again, when the direct benefit from increased effort is larger for the user than for the servitizing provider, the latter is less induced to reduce the servitizing price to incentivize the user's high effort.

A second observation concerning the servitizing provider's pricing decision is that the servitizing price is strictly increasing in the interest rate under both effort settings. This is obvious as a higher interest rate essentially increases unit production cost and the servitizing provider reacts by adjusting its servitizing price accordingly.

Using the insights about those pricing decisions we can now turn to the optimal effort choice of the user. In order to rule out the uninteresting case where

Table 2 Optimal pricing, and effort choices under bank finance

Finance strategy	Interest rate	User's effort	Optimal servitizing price f_{ib}	Optimal retail price p_{ib}
Bank finance	$0 \le r_b \le \underline{r}$	High effort	$\frac{1}{2}(1+(1+r_b)g+m_h)$	$\frac{1}{4}(3+(1+r_b)g+m_h)$
	$\underline{r} < r_b \le \bar{r}$	Induced high effort	$1-\frac{2a}{\bar{c}}-\frac{\bar{c}}{2}$	$1-\frac{a}{\bar{c}}-\frac{\bar{c}}{4}$
	$\bar{r} < r_b < \hat{r}_b$	Low effort	$\frac{1}{2}(1-\bar{c}+(1+r_b)g+m_l)$	$\frac{1}{4}(3+\bar{c}+(1+r_b)g+m_l)$

$\underline{r} = \frac{-4a+\bar{c}-\bar{c}^2-\bar{c}g-\bar{c}m_h}{\bar{c}g}$

$\bar{r} = \frac{-4a+\bar{c}-2\bar{c}^2-\bar{c}g-\bar{c}m_l}{\bar{c}g} + \sqrt{2}\sqrt{\frac{(4a+\bar{c}^2)(\bar{c}+m_l-m_h)}{\bar{c}g^2}}$

$\hat{r}_b = \frac{1-\bar{c}-k-m_l}{g}$

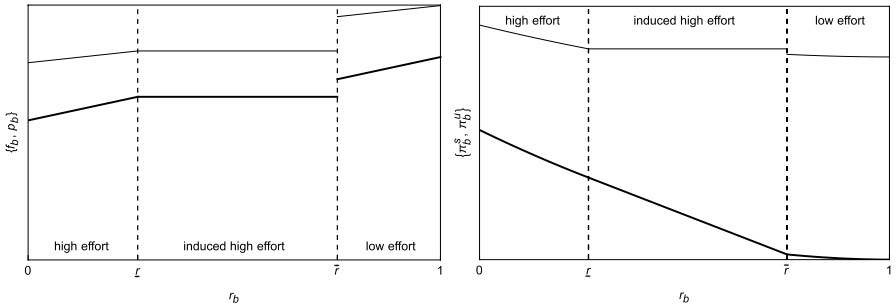


Fig. 1 Decisions and profits under bank finance
left panel: Consumer (thin) and servitizing prices (bold)
right panel: user (thin) and servitizing provider's (bold) profits
($K = 0.04, r_a = 0, m_l = 0.2, \bar{c} = 0.1, a = 0.0065, g = 0.348, m_h = 0.1995$)

inducing low effort is never optimal for the manufacturer under bank finance, we focus on the situation where $r_b < \hat{r}_b$, i.e. the bank interest rate is not prohibitively high.

Lemma 3 (User's optimal effort choice under bank finance) *Under bank finance the servitizing provider induces high effort e_h when the interest rate r_b is sufficiently low, i.e. $r_b \le \bar{r}$. Otherwise the servitizing provider induces low effort e_l.*

Corollary 1 *High effort can only be achieved with the locally optimal price given in Lemma 2 when the interest rate r_b is sufficiently low, i.e. $r_b \le \underline{r}$. Otherwise, i.e. when $\underline{r} < r_b \le \bar{r}$, the servitizing provider needs to set the lower price $\bar{f}_b$ to induce high effort.*

Corollary 2 *The profits of the servitizing provider as well as the user are weakly decreasing in the interest rate r_b.*

The thresholds as well as all the optimal prices are shown in Table 2.

As shown in Lemma 3, Corollary 1 as well as Fig. 1, the user has less incentive to exert high effort when the interest rate is increasing. Under a low interest rate, the servitizing provider's production cost is small and consequently he can afford to offer a lower servitizing price to the user, thereby incentivizing high effort. When the interest rate increases, the servitizing provider finds it more difficult to keep servitizing price down due to the production cost increase. Unless the interest rate becomes too high, the servitizing provider prefers deviating a little from his locally optimal servitizing price in order to still induce the user to exert high effort, but when interest rate increases further, the servitizing provider accepts low effort and sets a higher servitizing price to cover the increased maintenance cost associated with low effort by the user.

From Corollary 2 it follows that the financially constrained servitizing provider causes the entire supply chain to lose profit due to the higher prices. Before we move on let us establish one more benchmark, namely the situation where the servitizing provider is not financially constrained. In our model this is reflected simply by setting $r_b = 0$. The following lemma summarizes the insights.

Lemma 4 (Prices and effort when the servitizing provider is not financially constrained) *When* $r_b = 0$,

- The user exerts high effort iff $\underline{r} \geq 0$. This implies $0 < a \leq \frac{\bar{c}}{4}(1 - \bar{c} - g - m_h)$. The servitizing price is $f_h = \frac{1}{2}(1 + g + m_h)$, the consumer price is $p_h = \frac{1}{4}(3 + g + m_h)$.
- The user needs to be induced to exert high effort, iff $\underline{r} < 0 \leq \bar{r}$. This implies $\frac{\bar{c}}{4}(1 - \bar{c} - g - m_h) < a \leq \frac{\bar{c}}{4}(1 - \bar{c} - g - m_h) + \frac{\bar{c}\sqrt{(\bar{c}+m_l-m_h)(2-\bar{c}-2\,g-m_l-m_h)}}{4}$. The servitizing price is $f_h = 1 - \frac{2a}{\bar{c}} - \frac{\bar{c}}{2}$, the consumer price is $p_h = 1 - \frac{a}{\bar{c}} - \frac{\bar{c}}{4}$.
- The user exerts low effort, iff $\bar{r} < 0$. This implies $a > \frac{\bar{c}}{4}(1 - \bar{c} - g - m_h) + \frac{\bar{c}\sqrt{(\bar{c}+m_l-m_h)(2-\bar{c}-2\,g-m_l-m_h)}}{4}$. The servitizing price is $f_l = \frac{1}{2}(1 - \bar{c} + g + m_l)$, the consumer price is $p_l = \frac{1}{4}(3 + \bar{c} + g + m_l)$.

Trivially, as the cost of effort a increases, the user will reduce effort.

4.2 Optimal decisions of the servitizing provider and the user under user-direct finance

Turning to direct finance, we will – analogously to above – first characterize the optimal prices set by the user and the servitizing provider under low and high effort, respectively. Then we analyze the optimal effort choice for the user.

Lemma 5 (User's reaction under direct finance) *Under direct finance the user's optimal consumer price is given by* $p_{id} = \frac{1+f_{id}+c_i+(r_a-r_d)g}{2}$, *with* $i \in \{l, h\}$. *The user*

chooses high effort e_h, *if* $f_{hd} \leq \bar{f}_d$ *where* $\bar{f}_d = 1 - \frac{2a}{\bar{c}} - \frac{\bar{c}}{2} - g(r_a - r_d)$. *Otherwise she chooses low effort* e_l.

Besides the same observations already made from Lemmas 1, 5 shows that the user adjusts her consumer price proportionally to the opportunity cost associated with financing the servitizing provider. If lending to the servitizing provider is more profitable than the alternative investment ($r_d > r_a$), then the consumer price is reduced to stimulate demand and induce more business with the servitizing provider. Alternatively, if the user forgoes interest income by lending to the servitizing provider she will increase her consumer price, to reflect these additional *cost*. Similarly, the threshold on the servitizing price up to which the user will exert high effort is increased when $r_d > r_a$ and reduced when $r_d < r_a$. In the former case, as the business with the servitizing provider is financially attractive, the user is more willing to exert high effort to further improve the profitability of the relationship. Conversely, when $r_d < r_a$ high effort inducing lower prices and higher demand would only increase the amount of money diverged from the–more profitable–alternative investment.

The next result summarizes the servitizing provider's pricing decision.

Lemma 6 (servitizing provider's pricing decision under direct finance) *Under direct finance the supplier's locally optimal servitizing price is given by* $f^*_{id} = \frac{1-c_i+(1-r_a)g+m_i}{2} + r_d g$, *for* $i = h, l$.

Corollary 3 *Under direct finance the servitizing provider fully passes on any increase in the interest rate* r_d *to the user through an asscociated increase in the servitizing price. As a result the user's consumer price and consequently demand are unaffected by the interest rate* r_d.

Once again, Lemma 6 confirms the results from Lemma 2 also for direct finance. Additionally, as highlighted by Corollary 3, we find that the actual choice of the interest rate r_d is irrelevant, as the user's increased income from a higher interest rate is completely offset by the increased unit cost due to the servitizing price. The servitizing provider can do so as he anticipates the consumer price reaction of the user, who has therefore no power to control the supply chain with the interest rate r_d. Further, since consumer demand is not affected, r_d does not affect profitability of either user or servitizing provider. As a consequence, the actual decisions and firm profits only depend on the interest rate r_a, that captures the performance of any alternative investment the user could undertake rather than financing the servitizing provider. Yet, it is this interest rate r_a that provides a lever for the user over the servitizing provider. Specifically, we find that the locally optimal servitizing price is decreasing in this interest rate r_a. In other words, the user's outside option induces the servitizing provider to lower its servitizing price. He does so to make the servitizing agreement more attractive to the user and stimulate demand.

Table 3 Optimal pricing, and effort choices under direct finance

Finance strategy	Interest rate	User's effort	Optimal servitizing price f_{id}	Optimal retail price p_{id}
Direct finance	$0 \le r_a \le \underline{r}$	High effort	$\frac{1}{2}(1+(1-r_a)g+m_h)+r_d g$	$\frac{1}{4}(3+(1+r_a)g+m_h)$
	$\underline{r} < r_a \le \bar{r}$	Induced high effort	$1-\frac{2a}{\bar{c}}-\frac{\bar{c}}{2}-g(r_a-r_d)$	$1-\frac{a}{\bar{c}}-\frac{\bar{c}}{4}$
	$\bar{r} < r_a < \hat{r}_b$	Low effort	$\frac{1}{2}(1-\bar{c}+(1-r_a)g+m_l)+r_d g$	$\frac{1}{4}(3+\bar{c}+(1+r_a)g+m_l)$

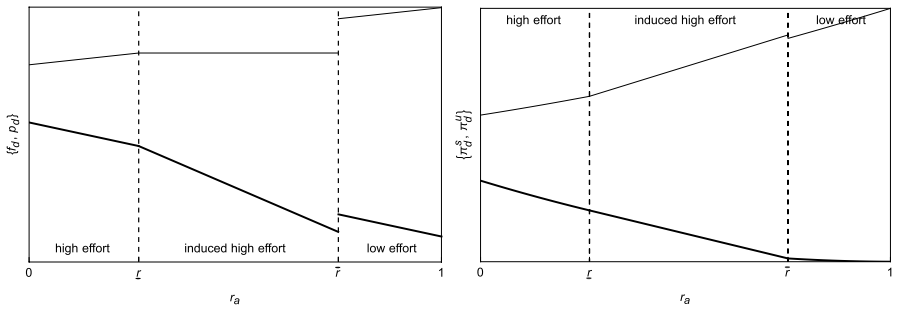


Fig. 2 Decisions and profits under direct finance
left panel: Consumer (thin) and servitizing prices (bold)
right panel: user (thin) and servitizing provider's (bold) profits
($K = 0.04, r_d = 0, m_l = 0.2, \bar{c} = 0.1, a = 0.0065, g = 0.348, m_h = 0.1995$)

Using the insights about those pricing decisions we can now turn to the optimal effort choice of the user.

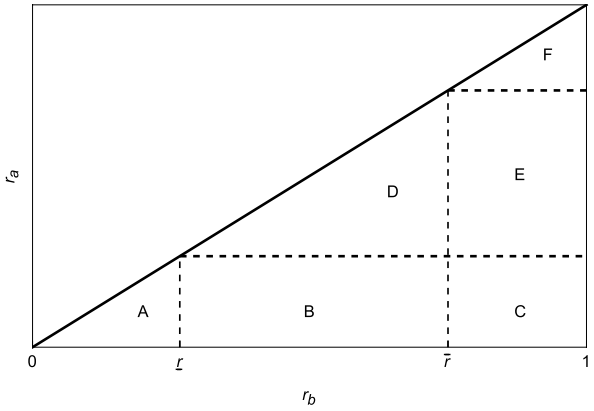
Lemma 7 (User's optimal effort choice under direct finance) *Under direct finance the servitizing provider induces high effort e_h when the interest rate r_a of the alternative investment is sufficiently low, i.e. $r_a \le \bar{r}$. Otherwise the servitizing provider induces low effort.*

Whenever r_a is sufficiently low, i.e. $r_a \le \underline{r}$, the locally optimal servitizing price given in Lemma 6 ensures high effort by the user. If $\underline{r} < r_a \le \bar{r}$, the servitizing provider needs to set the lower price $\bar{f}_d$ to induce high effort.

Corollary 4 *The associated thresholds $\underline{r}$ and $\bar{r}$ are identical to the ones under bank finance.*

Corollary 5 *The profit of the servitizing provider is strictly decreasing in the interest rate r_a. The profit of the user is strictly increasing in the interest rate r_a except at the point where she switches from induced high effort to low effort.*

All the optimal prices are shown in Table 3.



A: high effort under both settings
B: high effort under direct finance, induced high effort under bank finance
C: high effort under direct finance, low effort under bank finance
D: induced high effort under both settings
E: induced high effort under direct finance, low effort under bank finance
F: low effort under both settings

Fig. 3 Comparison of user's effort choice between direct finance and bank finance as a function of r_a and r_b

These results show that while the user does not find the interest rate r_d to be a lever, her effort decision is driven by the profitability of the outside option in the form of the interest rate r_a. In analogy to what has been discussed about the results in Lemma 5, an increased value of the alternative investment leads the user from exerting high effort to exerting low effort. This makes the servitizing arrangement less profitable and consequently reduces its scope, thereby diverting less money from the alternative investment.

Finally, trivially the user benefits from a more financially attractive outside option, while the servitizing provider suffers due to its reduced bargaining power (Fig. 2). Below we will investigate whether and if so how this tension can affect the supply chain strategies of the two firms compared to bank finance.

4.3 Impact of different financing strategies on user's effort

As we know from the literature review, supply risk can not be mitigated under buyer direct finance (user-direct finance in our model) due to the contingent nature of the supply contract when there is no information asymmetry (Tang et al. 2018). The question is whether the same logic applies in our setting. While there is also no information asymmetry in our setting, the decision making logic differs in two important ways. First, the servitizing provider can set the optimal servitizing price for a given high or low effort case without information asymmetry. Second, the moral hazard is on the user side and associated with her effort choice.

The following result provides a strong answer to this question.

Proposition 1 *Bank finance can never lead to higher effort than direct finance. Conversely, direct finance leads to higher effort than bank finance if* $r_a < \bar{r} < r_b$. *Otherwise, the choice of finance scheme does not affect effort.*

Corollary 6 *When* $r_a < \underline{r} < r_b \leq \bar{r}$ *both financing options lead to high effort. Yet under direct finance this high effort is achieved with the locally optimal price* f^*_{hd}, *while under bank finance the servitizing provider has to set the threshold price* $\bar{f}_b$ *to induce the user accordingly.*

The results in Proposition 1 and Corollary 6 follow directly from Lemmas 3 and 7 and the associated corollaries. Our results indicate that direct finance can never be counterproductive in terms of inducing effort. Rather, since the interest rate thresholds differentiating between high and low effort are independent of the financing scheme, and $r_a < r_b$, direct finance can indeed induce the user to exert high effort when she would not do so under bank finance. Figure 3 visualizes the result. Importantly, the benefit of direct finance in terms of inducing high effort increases as the interest differential $r_b - r_a$ increases. As mentioned before, when the outside option for the user is less attractive, high effort becomes more likely stressing the link between the decision making in the physical market with the financial market. This is also reflected in the other decision of the user namely the consumer price. It turns out consumer price is never larger under direct finance than under bank finance. In fact it is always strictly smaller, unless both financing schemes lead to high effort induced by the threshold price $\bar{f}_b$. In that case the consumer price is unchanged. Consequently, demand is non-decreasing under direct finance compared with bank finance. Given those positive effects the question remains whether direct finance can completely eliminate the disadvantages associated with the financially-constrained servitizing provider. The following lemma summarizes the associated insight.

Lemma 8 *Under direct finance the servitizing provider acts as if it were not financially constrained only if* $r_a = 0$.

Thus, only if the user does not have a profitable outside option the interests of both firms are aligned and the capital-constraint is effectively eliminated. Otherwise, the user extracts some extra profit from the supply chain through the threat of its outside option.

4.4 Servitizing provider's preferences over and user's choice of financing option

The above results lead to another interesting question, namely whether direct finance will ensue at all. To do so, both firms will have to prefer direct finance over bank finance. In other words, will the servitizing provider accept direct finance if he has

Table 4 Optimal profits of the two firms in the two financing schemes under different levels of effort

User's effort	Firm profits	Financing scheme	
		Bank finance	Direct finance
High effort	Servitizing provider	$\frac{1}{8}(1-m_h-g(1+r_b))^2$	$\frac{1}{8}(1-m_h-g(1+r_a))^2$
	User	$\frac{1}{16}((1-m_h-g(1+r_b))^2-16a)+Kr_a$	$\frac{1}{16}((1-m_h-g(1+r_a))^2-16a)+Kr_a$
Induced high effort	Servitizing provider	$\frac{(4a+\bar{c}^2)(\bar{c}(2(1-m_h-g(1+r_b))-\bar{c})-4a)}{8\bar{c}^2}$	$\frac{(4a+\bar{c}^2)(\bar{c}(2(1-m_h-g(1+r_a))-\bar{c})-4a)}{8\bar{c}^2}$
	User	$\frac{(4a-\bar{c}^2)^2}{16\bar{c}^2}+Kr_a$	$\frac{(4a-\bar{c}^2)^2}{16\bar{c}^2}+Kr_a$
Low effort	Servitizing provider	$\frac{1}{8}(1-\bar{c}-m_l-g(1+r_b))^2$	$\frac{1}{8}(1-\bar{c}-m_l-g(1+r_a))^2$
	User	$\frac{1}{16}(1-\bar{c}-m_l-g(1+r_b))^2+Kr_a$	$\frac{1}{16}(1-\bar{c}-m_l-g(1+r_a))^2+Kr_a$

the choice between direct finance and bank finance? And should the user offer direct finance or let the servitizing provider borrow money from the bank?

Table 4 shows the profits of the two firms under the different levels of effort for both financing options and Proposition 2 summarizes the strong findings in terms of the profit comparison between the two financing schemes.

Proposition 2 *Both the servitizing provider and the user always prefer direct finance over bank finance.*

From Table 4 we observe that the profits are structurally identical between direct finance and bank finance, where r_a replaces r_b under direct finance. Since $0 \leq r_a \leq r_b$ by definition, we can see that for a given effort, i.e. in regions A,D and F shown in Fig. 3, profits are always larger for the servitizing provider and never smaller for the user under direct finance. For the remaining three cases (B,C and E), where effort is larger under direct finance than under bank finance the results for both firms actually follow directly from Corollary 2 as their profits are weakly decreasing in r_b, and $r_a \leq r_b$ magnifies this effect.

Summarizing, Proposition 2 implies that direct finance provides a win-win solution for the two firms. One driver for this is that consumer price is never larger under direct finance as established in the previous section. Thus, there is a demand enhancing effect of direct finance. Additionally we find that the per-unit revenue of both firms is strictly larger under direct finance than under bank finance. This implies that the reduced financing cost induced by the lower interest rate r_a under direct finance is shared by the two firms. However, this also implies that as the outside option for the user becomes more profitable, i.e. r_a increases, both firms lose profit. When $r_a = r_b$ both firms are indifferent between the financing options and the individual and joint profits are lowest.

While these results imply that reducing the financial constraint within a supply chain will benefit both firms, the increased demand associated with that has

diverging effects on the social and environmental dimension of the triple bottom line. While consumer surplus increase along firm profits when the servitizing providers' access to finance is improved, i.e. interest rates are lower, the demand effect implies that resource consumption increases, which may not be preferable from an environmental perspective.

5 Extension: the case of continuous effort

To check the robustness of our main findings above, we will analyze the implications of considering continuous effort levels e in our model. As mentioned in the model description, the effort level affects the profitability of the servitizing provider and the servitized user in three ways. First, for the servitized user exerting effort is costly and we assume the quadratic function ae^2. Second, on the positive side, higher effort reduces the servitized user's operating cost, and we assume the form $c(1-e)$. These model components are unchanged for this model extension. Third, the servitizing provider observes maintenance cost as a function of the user's effort. Here, our main model just distinguished between high and low maintenance cost under low and high effort, respectively, and did not utilize a specific functional form. To keep things simple and in line with the remaining model structure we extend our model by considering the following functional relationship between effort and maintenance cost: $m(1-e)$. Here m corresponds to the maintenance cost when no effort is exerted ($e=0$), i.e. $m=m_l$ replicates this situation from our main model. Apart from that, this form clearly preserves the property that higher effort implies lower maintenance cost and this positive effect is symmetric to the servitized user's positive effect in terms of operating cost. All the other model components remain unchanged.

Thus, the servitizing provider's decisions are driven by the maximization of the following profit function:

$$\pi_j^s = (f_j - m(1-e) - g - gr_j)(1-p_j), \quad j \in \{b,d\}. \tag{4}$$

The user's profit as a function of her decisions p and e under bank finance is given by:

$$\pi_b^u = (p_b - f_b - c(1-e))(1-p_b) - ae^2 + Kr_a. \tag{5}$$

The user's profit as a function of her decisions p and e under user-direct finance is given by:

$$\pi_d^u = (p_d - f_d - c(1-e))(1-p_d) - ae^2 + Kr_a + g(1-p_d)(r_d - r_a). \tag{6}$$

To keep the analysis simple, and in line with its main intention to just check the robustness of our main results under binary effort, we use some further assumptions. First, analyzing the profit functions yields that for concavity, and consequently optimal results, the condition $a > \frac{c^2}{4}$ is required. Thus, we will restrict our analysis to this case. Second, to simplify the analysis under user-direct finance, we assume

Table 5 Optimal pricing, and effort choices under bank finance and user-direct finance

Finance strategy	Interest rate	User's effort	Optimal servitizing price f_b	Optimal retail price p_b
Bank finance	$0 \le r_b \le min[\underline{r}', \bar{r}']$	High effort $e = 1$	$1 - \frac{4a}{c}$	$1 - \frac{2a}{c}$
	$min[\underline{r}', \bar{r}'] < r_b \le \hat{r}_b'$	Low effort $e = \frac{c(1-c-g-m-gr_b)}{8a-2c(c+m)}$	$\frac{(4a-c^2)(1-c+(1+r_b)g+m)-2mc(1-c)}{8a-2c(c+m)}$	$1 - \frac{a(1-c-(1+r_b)g-m)}{4a-c(c+m)}$
Direct finance	$0 \le r_a \le min[\underline{r}', \bar{r}']$	High effort $e = 1$	$1 - \frac{4a}{c} + g(-r_a + r_d)$	$1 - \frac{2a}{c}$
	$min[\underline{r}', \bar{r}'] < r_a \le \hat{r}_b'$	Low effort $e = \frac{c(1-c-g-m-gr_a)}{8a-2c(c+m)}$	$\frac{(4a-c^2)(1-c+(1-r_a)g+m)-2mc(1-c-gr_a)}{8a-2c(c+m)} + r_d g$	$1 - \frac{a(1-c-(1+r_a)g-m)}{4a-c(c+m)}$

$\underline{r}' = \frac{-4a+c-cg}{cg}$

$\bar{r}' = \frac{-8a+c+c^2-cg+cm}{cg}$

$\hat{r}_b' = \frac{1-c-g-m}{g}$

$r_d < r_a$ which is consistent with the parameters we use when graphing the main results in the main analysis and also makes practical sense. Third, in order to rule out the uninteresting case where the servitizing provider does not make any profit, we focus on the situation where $r_b < \hat{r}_b'$, i.e. the bank interest rate is not prohibitively high.

Tables 5 and 6 provides information about the optimal decisions as well as associated profits of both the servitizing provider and the servitized user. We first observe that it is never optimal for the user to exert no effort at all, i.e. $e = 0$ is not a solution in either financing situation. Conversely, highest effort $e = 1$ exists as part of the optimal strategy space, such that the distinction is now between $e = 1$ and $0 < e < 1$. Here, the second observation is that structurally identical dynamics are at work. When the interest rate is increasing the users have an incentive to reduce effort.

With this insight we can now revisit our two main results from Propositions 1 and 2. With respect to Proposition 1, we first observe that the threshold between $e = 1$ and $0 < e < 1$ is still identical between the two financing schemes. Second, as the thresholds are also again on r_b and r_a, this further implies that the general insight from Proposition 1 still holds. User-direct finance can encourage users to exert highest effort $e = 1$ when they would exert lower effort $0 < e < 1$ under bank finance. Even when it is optimal to exert effort $0 < e < 1$ under both financing schemes the effort exerted under user-direct finance is strictly larger than the effort exerted under bank finance.

By comparing the profits in Table 6 we find, analogously to Proposition 2, that user-direct finance never leads to lower profits than bank finance for either player. Consequently, both servitizing provider and servitized user always prefer user-direct finance over bank finance when considering continuous effort level e.

Summarizing, all our main structural insights from our model with binary effort, still hold in the same way under the extension of continuous effort level e.

6 Conclusion

In this paper we have considered a supply chain of a servitizing provider and a user, where the latter can impact the maintenance cost of the former by exerting effort in the careful use of the product. The former is financially constrained and needs to borrow money to cover its manufacturing cost for supplying the servitized product. He can do so by taking out a bank loan or (if offered by the user) by borrowing directly from the user. In this setting we have analyzed how the user's effort is affected by the fact that the servitizing provider is financially constrained and found that all else equal, the user will exert less effort when the cost of borrowing increases. We have also studied whether direct finance can affect this effort reduction and found that indeed effort can never be smaller under direct finance than under bank finance and will often be strictly larger. Finally, we examined whether direct finance will be offered at all by the user and if so if it will be accepted by the servitizing provider. Here we found that both firms always benefit from direct finance. As our main model is based on the assumption of binary effort levels $e = 0$ or $e = 1$, in an extension we checked how robust our

Table 6 Optimal profits of the two firms in the two financing schemes under different levels of effort

User's effort	Firm profits	Financing scheme	
		Bank finance	Direct finance
High effort	Servitizing provider	$\frac{2a(c(1-g-gr_b)-4a)}{c^2}$	$\frac{2a(c(1-g-gr_a)-4a)}{c^2}$
	User	$a(-1+\frac{4a}{c^2})+kr_a$	$a(-1+\frac{4a}{c^2})+kr_a$
Low effort	Servitizing provider	$\frac{a(1-c-g-m-gr_b)^2}{8a-2c(c+m)}$	$\frac{a(1-c-g-m-gr_a)^2}{8a-2c(c+m)}$
	User	$\frac{4kr_a(c(c+m)-4a)^2+(4a^2-ac^2)((1-c-g-m)-gr_b)^2}{4(4a-c(c+m))^2}$	$\frac{4kr_a(c(c+m)-4a)^2+(4a^2-ac^2)((1-c-g-m)-gr_a)^2}{4(4a-c(c+m))^2}$

results are when this assumption is dropped and effort levels can be chosen continuously. We found that all our results are structurally identical.

Our results imply that direct financing within a supply chain can help reduce some of the inefficiencies that may arise due to lack of capital and that all involved parties can benefit from it. However, as long as the lending side incurs opportunity cost by financing a supply chain partner, the inefficiencies can not be fully removed.

Our research can be extended in several ways. First, as a starting point we have assumed that user effort is perfectly observable by the servitizing provider. It should be interesting to study how our insights would change when the servitizing provider can not know with certainty whether high maintenance cost was really caused by low effort on the side of the user. The resulting dynamics with respect to the choice of the servitizing price, the effort it induces and the associated value of direct finance over bank finance could extend our understanding of the servitizing business model and its implications. Second, we have assumed that the quality of the servitized product is exogeneously given. In practice, the servitizing provider may be able to improve the durability and reliability of the product thereby affecting the maintenance cost by product design. However, given that such design efforts may be costly, the financial limitations of the servitizing provider will become more pronounced. As such, one could expect that direct finance could become even more favourable as it already is in our setting. However, since product design improving durability and/or reliability will interact with the user's effort in affecting maintenance cost, it remains unclear how user's effort will change as a result of the product design. Studying this would be interesting in the perfect information setting used in our paper, but could provide even more intricate insights under information asymmetry as mentioned in our first suggested extension above.

Appendix

Proof of Lemma 1 The user's profit function $\pi^u_{ib} = (p_{ib} - f_{ib} - c_i)(1 - p_{ib}) - ae_i^2 + Kr_a$ is concave in consumer price p. Solving the first-order condition $\frac{\partial \pi^u_{ib}}{\partial p_{ib}} = 1 + c_i + f_{ib} - 2p_{ib} = 0$, we have $p^*_{ib} = \frac{1+f_{ib}+c_i}{2}$ for $i = h, l$. Plugging the optimal consumer price p^*_{ib} into π^u_{ib} function and comparing the user's profits under high effort and low effort cases, we know

that when $f_{hb} \leq \bar{f}_b = 1 - \frac{2a}{\bar{c}} - \frac{\bar{c}}{2}$, the user chooses to exert high effort, otherwise the user exerts low effort.

Proof of Lemma 2 We insert the optimal price p^*_{ib} into the servitizing provider's profit function for $i = h, l$. By calculating the second derivative, we find that the servitizing provider's profit π^s_{ib} is concave in servitizing price f^*_{ib}, for $i = h, l$. Solving the first-order condition $\frac{\partial \pi^s_{ib}}{\partial f_{ib}} = 0$ we get the locally optimal servitizing price $f^*_{ib} = \frac{1}{2}(1 - c_i + (1 + r_b)g + m_i)$ for $i = h, l$.

Proof of Lemma 3 Under the high effort case, the locally optimal servitizing price f^*_{hb} needs to satisfy the conditions $0 < f_{hb} < 1$ and $f_{hb} \leq \bar{f}_b = 1 - \frac{2a}{\bar{c}} - \frac{\bar{c}}{2}$. Therefore, the Lagrangian function of the servitizing provider is $L_{hb} = \pi^s_{hb} + \lambda_1(f_{hb}) - \lambda_2(f_{hb} - \bar{f}_b) - \lambda_3(f_{hb} - 1)$. Solving the first-order condition $\frac{\partial L_{hb}}{\partial f_{hb}} = 0$ we get the optimal servitizing price $f^*_{hb} = \frac{1}{2}(1 + (1 + r_b)g + m_h)$., for the case $f_{hb} \leq \bar{f}_b$ is satisfied, we have $r_b < \frac{-4a+\bar{c}-\bar{c}^2-\bar{c}g-\bar{c}m_h}{\bar{c}g}$. If $\frac{-4a+\bar{c}-\bar{c}^2-\bar{c}g-\bar{c}m_h}{\bar{c}g} < r_b < \frac{-4a+2\bar{c}-\bar{c}^2-2\bar{c}g-2\bar{c}m_h}{2\bar{c}g}$, then $f^*_{hb} = \bar{f}_b = 1 - \frac{2a}{\bar{c}} - \frac{\bar{c}}{2}$. Then we substitute the optimal servitizing price f^*_{hb} into $p^*_{hb} = \frac{1+f_{hb}}{2}$, thereby obtaining the optimal consumer price p^*.

Proof of Lemma 4 By plugging $r_b = 0$ into $r_b \leq \underline{r}$, $\underline{r} < r_b \leq \bar{r}$, $\bar{r} < r_b$, we can get the conditions when the user exerts high effort, the servitizing provider induces high effort, and the user exerts low effort. Plugging $r_b = 0$ into the optimal servitizing and consumer prices from Lemmas 2 and 3 yields the optimal servitizing price and consumer price when $r_b = 0$.

Proof of Lemma 5 The user's profit function $\pi^u_{id} = (p_{id} - f_{id} - c_i)(1 - p_{id}) - ae_i^2 + \frac{2a}{\bar{c}} - \frac{\bar{c}}{2}$ is concave in consumer price p_{id}. Solving the first-order condition $\frac{\partial \pi^u_{id}}{\partial p_{id}} = 0$, we have $p^*_{id} = \frac{1+f_{id}+c_i+(r_a-r_d)g}{2}$ for $i = h, l$. Plugging the optimal consumer price p^*_{id} into π^u_{id} function and comparing the user's profits under high effort and low effort cases, we know that when $f_{hd} \leq \bar{f}_d = 1 - \frac{2a}{\bar{c}} - \frac{\bar{c}}{2} - g(r_a - r_d)$, the user chooses to exert high effort, otherwise the user exerts low effort.

Proof of Lemma 6 and Lemma 7 The proofs run along the same lines as the proofs for Lemmas 2 and 3.

Proof of Proposition 1 The result follows directly from Lemmas 3 and 7.

Proof of Lemma 8 By comparing the profits of the servitizing provider, we can find that: the servitizing provider has the same profits when $r_b = 0$ and $r_a = 0$, the profit

of servitizing provider is $\frac{(1-m_h-g)^2}{8}$ under high effort case, $\frac{(4a+\bar{c}^2)(\bar{c}(2(1-m_h-g-\bar{c})-4a)}{8\bar{c}^2}$ under induced high effort case, $\frac{(1-\bar{c}-m_l-g)^2}{8}$ under low effort case. We know that the servitizing provider is not financially constrained when $r_b = 0$, which implies that the servitizing provider acts as it was not financially constrained only if $r_a = 0$.

Proof of Proposition 2 By comparing the profits of the servitizing provider and the user under both financing strategies, we know that profits of servtizing firm and users are structurally identical between direct finance and bank finance, only where r_b is replaced by r_a, so we get $\pi^s_{id} > \pi^s_{ib}$ and $\pi^u_{id} > \pi^u_{ib}$, when we have $r_a \leq r_b$.

Proof of Tables 5 and 6 in the extension.

Under the bank finance, the user's function $\pi^u_b = (p_b - f_b - c(1-e))(1-p_b) - ae^2 + Kr_a$ is jointly concave in consumer price p and effor level e. Solving first-order condition we can have $p^*_b = \frac{-2a-2ac+c^2-2af}{4a-c^2}$ and $e^* = -\frac{c(-1+c+f)}{4a-c^2}$. Plugging the optimal consumer price p^*_b and e^* into the servitizing provider's profit function $\pi^s = (f - m(1-e) - g(1+r))(1-p)$, when $\frac{-4a+c}{c} < f < 1-c$, we have $0 < e < 1$, when $f \leq \frac{-4a+c}{c}$, $e = 1$. Solving the first-order condition, we get the locally optimal servitizing price $f^* = \frac{4a(1-c+g+m+gr_b)+c(-2m+c(-1+c+m-g(1+r_b)))}{8a-2c(c+m)}$ when $0 < e < 1$, $f^* = \frac{-4a+c}{c}$ when $e = 1$. Then substitute optimal f^* into the function of optimal p^*_b, e^* and profit function to get the optimal p^* and optimal profit.

The proofs for user-direct finance run along the same lines as the proofs for bank finance.

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Declarations

Conflict of interest All authors declare that they have no conflicts of interest.

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