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When is servitization a profitable competitive strategy?

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ABSTRACT

Although servitization has emerged as a new competitive strategy for manufacturers, there has been little research about product-level servitization. We investigate the competition between two channels, one separately providing both goods and services and the other providing inseparable servitized goods through a game theoretic approach. Two critical parameters to understand competition between the two channels will be proposed: (1) service dependency – a degree of dependency of physical goods upon services – and (2) channel substitutability – a degree of substitution between conventional channels and servitized one. The study reveals that the servitization strategy is a better choice for a manufacturer selling physical goods only when the goods require a higher level of service (i.e., high service dependency), and when the competition between the two channels is more severe (i.e., high channel substitutability). In addition, obtaining cost efficiency is found to be an important factor to achieve higher competitive advantage over the other channel.

1. Introduction

In more competitive markets, manufacturers have begun to offer products with services in inseparable formats to gain a competitive advantage to survive the market. More manufacturers are providing their customers with an opportunity to obtain highly integrated services. The term *servitization* has been used in both academia and practice to capture this phenomenon in which manufacturing companies provide services as an important strategy (Vandermerwe and Rada, 1988). For example, Rolls-Royce now earns higher revenue not from selling aircraft engines but from providing services such as maintenance and repair. Adobe no longer only sells desktop applications to attract more customers. Creative Cloud by Adobe provides access to the latest versions of the company's various programs as well as appropriate services for making the programs more efficient and valuable. Now the number of subscribers for Creative Cloud has increased up to almost 4 million (ProDesignTools, 2014) and the stock price has risen around 130% in the last 3 years. Xerox is no longer just a copier manufacturer but has transformed itself into a company that provides "document solutions" based on fees by copy machine usage.

There are various definitions of servitization in the literature, with narrow or broad views. Vandermerwe and Rada (1988) coined the term servitization evolving in three stages: Stage 1 (goods or services), Stage 2 (goods and services), and Stage 3 (goods and services combined with support, knowledge, and self service). Robinson et al. (2002) defined servitization as the inextricably linked status of the core product and the service elements. Neely (2008) defined servitization as a firm's capabilities and competencies that create mutual value not by selling products alone but by selling product-service systems (PSS). Quinn et al. (1989) explained that the services in the manufacturing industry are essential and not separate[2]. As the economic environment changes, recently the servitization strategy is implemented under the situation that big data have a big role (Opresnik and Taisch, 2015). We examine product-level servitization rather than firm- or industry-level one. Servitized goods in this study are defined as goods integrated with and inseparable from services that have additional and supplementary characteristics such as maintenance, repair, and after-sales service for consumer convenience.

Simon and Wuebker (1999) proposed various rationales for bundling: price discrimination, complexity cost reduction, economies of scope and scale, transaction cost reduction, among others.

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[2] For more extensive reviews on the definition of servitization, see Ryu et al. (2012).

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They also provided many forms of bundling according to its implications: pure bundling, mixed bundling, tie-in sales, add-on bundling, sales rebates, and cross-couponing (Simon and Wuebker, 1999). Servitization is similar as bundling because servitization can be explained as a package of goods and services (Vandermerwe and Rada, 1988; Johnson and Mena, 2008). It is thus a type of mixed bundling for providing goods and services. The services in servitization, however, should depend on products in a strong way; thus, add-on bundling, in which the add-on goods are not saleable until the main goods are purchased by the consumers, is similar to servitization. The product-level servitization should be distinguished from bundling, also a managerial selection for providing goods and/or services in one package. We assume that "servitized" products are not a simple combination of goods and services but an inseparable transformation that has its own characteristics.

Though many articles have pointed out the empirical relationship between servitization and firm profitability (e.g., Visnjic Kastalli and Van Looy, 2013), little research has investigated conditions that make product-level servitization [i.e., "Stage 2 or 3 servitization" in Vandermerwe and Rada (1988) or "integrated package" in Van Looy et al. (2003)] a profitable competitive strategy for a manufacturer. Rather, extant empirical literature operationally measures servitization as the ratio of service revenue for manufacturers (e.g., Visnjic Kastalli and van Looy, 2013; Fang et al., 2008; Han et al., 2013), the number of services offered (e.g., Neely, 2008), the number of service types (e.g., Li et al., 2015), or new service products by manufacturers (e.g., Falk, 2014). These studies have found that the relationship between servitization and firm performance is moderated by various factors such as product innovation, product complexity, business areas, organizational design, and the level of investment. For example, Malleret (2006) noted that offering services does not always guarantee profitable results because the appropriate strategy applying service provision depends on the management environment.

Therefore we ask the following straightforward research question: When is servitization a profitable competitive strategy? In this paper, we develop a mathematical model that examines competition between conventional (i.e., separately offering goods and services) and servitized (i.e., offering integrated goods and services) channels, and discuss a few critical strategic implications by various propositions. In this model, we pay attention to service dependency (i.e., the extent that service is required for utilizing goods) and channel substitutability (i.e., the extent that the servitized market and the conventional market can be substituted) to understand the outcome of the servitization strategy. This research contributes to the service and operations literature by theoretically investigating the channel conditions of superior competitiveness of servitization strategy under price and quality equilibrium. This research has also a practical value to identify the factors that influence the expected payoffs for a manufacturer considering a transition to servitization strategy.

This paper is organized as follows. The literature review will be covered in the next section, succeeding the above introduction. The model section consists of three subsections. First, Case 1 about the competition between the conventional channel (i.e., an independent manufacturer and a service provider exist) and the servitized channel will be provided. Second, Case 2 shows the situation where the manufacturer and the service provider in the conventional channel are integrated. Third, the benchmark case is compared with the alternative case. Lastly, the managerial implications, contributions, limitations, and future research directions will be discussed.

2. Literature review

The literature review is based on three research streams: servitization, bundling, and game theoretic channel analysis. Vandermerwe and Rada (1988) wrote a seminal paper that discussed how the manufacturing firm can obtain a competitive advantage through service. Anderson and Narus (1995) emphasized that services should be provided as a standard or as optional, for effectiveness and flexibility. Wilkinson et al. (2009) explained many terms related to the phenomenon in which product and service offerings are integrated, such as product-service system, integrated solutions, and servitization. A recent review by Harkonen et al. (2015) made distinction 'productisation' from servitization to explain a more general process of offering a product-like object to consumers by combining relevant elements.

Gebauer et al. (2011) summarized the effects of servitization on financial performance by measuring various indices of the servitization strategy while exploring the evolution of service strategy. Many researchers have found a positive relationship between servitization and firm performance. For example, Fang et al. (2008) found that a positive effect from servitization strategy takes place only after achieving a certain scale of service portion from the total revenue. However, there also exists a negative aspect of servitization due to diverse causes such as (1) additional investments for securing service-provision-related assets, and (2) the absence of a strategic focus by splitting firm resources (Neely, 2008; Visnjic Kastalli and Van Looy, 2013). Gebauer et al. (2005) also investigated the negative aspects of servitization and proposed a term "service paradox" that expected outcomes by servitization cannot be obtained by manufacturers while confronting with inefficient investment. Neely (2008) empirically validated with data for 10,634 firms that manufacturing firms might obtain lower profit in spite of higher revenue by applying the servitization strategy because higher labor costs and working capital are required. Malleret (2006) noted that offering services does not always guarantee profitable results because the appropriate strategy applying service provision depends on the management environment. Therefore, manufacturers considering servitization should thoroughly understand critical moderating factors that affect the relationship between servitization strategy and firm performance, and make appropriate adaptations such as costing practice optimization (Zhen, 2012; Settanni et al., 2014). Further, establishing supplier and buyer relationship in a servitized supply chain shows different patterns due to higher complexity than the traditional supply chain (Saccani et al., 2014).

Bundling has been studied as a common profit making strategy by combining complementary goods and services (e.g., Stigler, 1968; Adams and Yellen, 1976). There also have been many studies to investigate bundling in the channel context. For example, Bhargava (2012) investigated the differences among the distribution channel structures for product bundling, and Palsule-Desai et al. (2015) focused on the incremental value of add-on services on the core product. However, no studies can be found about the channel competition for servitized goods. Though product-level servitization can be seen as a type of bundling, there exists additional benefit from the services added to the products in servitization (Lin et al., 2011).

Many researchers have shown an interest in the game-theoretic approach for channels. McGuire and Staelin (1983) investigated the channel competition under two manufacturers and one retailer under the existence of product substitutability. Coughlan (1985) extended McGuire and Staelin's work (1983) while considering the empirical approach. In addition to these much-cited studies, various articles have been published regarding channel competition such as those by Gupta and Loulou (1998), Choi (1996), Chiang et al. (2003), Yan and Bandyopadhyay (2011), and Xie et al. (2011).

At present, more diverse channel characteristics such as online versus offline channels (Yao and Liu, 2005; Kurata et al., 2007), private versus public channels (Bian et al., 2015), and other factors besides price (Banker et al., 1998; Tsay and Agrawal, 2000) have been incorporated in the channel research. Cai (2010) studied the channel preferences which caused firms to introduce new channels. For example, companies such as Nike and Estée Lauder have adopted the Internet channel in addition to their off-line channel while Dell newly opened their off-line stores. The current paper deals with channel competition due to the launch of a new channel that carries fully-integrated servitized products.

In sum, this paper has a twofold contribution to the existing relevant literature. First, based on an analytical modeling, this paper provides more theoretically sound understanding about the competition between a conventional channel separately offering physical goods and services and a newly emerging channel offering fully-integrated servitized products. Since the existing literature is limited in conceptual or empirical approaches to investigate the servitization phenomenon, prescriptive policy implications can be hardly derived. Second, two important state variables that govern the economic performance of servitization are introduced and analyzed in this paper: service dependency and channel substitutability. Through these two variables, we attempt to reveal some necessary conditions for managers who intend to increase profitability by introducing servitized products.

3. Model setup

The proposed model shows the channel competition between two firms in the market in terms of price and quality. In a conventional channel, a manufacturer provides physical goods (G), and an independent service firm provides consumers with any required services (S). In a servitized channel however, a firm provides both goods and services at once as a servitized product (GS). Thus, the servitized firm competes with the union of a manufacturer and a service provider in the conventional channel.

A two-stage game will be played by the competitors. Firms simultaneously choose the quality levels at stage 1 and decide their prices at stage 2. Demand is realized based on these price and quality levels. Following Banker et al. (1998) and many other researchers thereafter (e.g., Bernstein and Federgruen, 2004), we model demand as a linear function of quality and price. See Huang et al. (2013) for a summary of a variety of demand functions in the literature.

There are two critical parameters to investigate the current research problem: service dependency (θ) and channel substitutability (ϕ). The service dependency parameter θ ($0 \le \theta \le 1$) refers to the degree of services required for utilizing goods well. As θ approaches 1, services are necessary and required for goods. On the other hand, a lower θ means lower dependence on services. For example, managing the photocopiers, such as supplying a toner, eliminating paper jams, installing local printer networks, can be done by users with some effort, so total document management services might not be required. However, maintaining aero engine systems should always be supplied for proper uses of goods, so service requirements are very high. Since it is regarded that services cannot exist without goods, the demand function for the service provider incorporates such dependence as in Eq. (1c). $\phi (0 \le \phi \le 1)$ is the level of substitutability between the servitized channel and the conventional one. As ϕ approaches 1, servitized products have higher substitutability with the conventional goods and services provided by manufacturers and service providers respectively. On the other hand, $\phi = 0$ means that the manufacturer and the servitized firm enjoy monopoly in their respective markets. For example, consumers who use cars can be divided into two groups: (i) a purchasing group and (ii) a leasing or renting group. The former is an example of conventional channels with independent manufacturers and service providers, and the latter is an example of a servitized channel where a car leasing company provides combined goods and services with a single fee. These two consumer groups usually do not switch to the other groups because there exist clear differences between these two markets.

Table 1
Terms definitions.

Terms	Definition
θ	Service dependency
ϕ	Substitutability between servitized and conventional channels
γ	Quality sensitivity
α_i	Market base ($i = G, S, GS$)
η_i	Quality cost coefficient ($i = G, S, GS$)
p_i	Price ($i = G, S, GS$)
q_i	Quality of goods ($i = G, S, GS$)
D_i	Demand for goods ($i = G, S, GS$)

*Note: subscript G stands for physical goods, S for services, and GS for servitized products.

Three demand functions for goods, services, and servitized goods are required because of their asymmetrical channel structures. In the conventional channel, α_G is defined as the market base for goods only, namely the intrinsic demand for goods. α_S is the market base for services only, but this is transformed into $\theta\alpha_G$ due to the market dependency of services. Based on the above coefficients, the following demand functions can be obtained:

$$D_G = \alpha_G - p_G - \theta p_S + \phi p_{GS} + \gamma(q_G + \theta q_S - \phi q_{GS}), \tag{1a}$$

$$D_{GS} = \alpha_{GS} - p_{GS} + \phi(p_G + \theta p_S) + \gamma(q_{GS} - \phi(q_G + \theta q_S)), \tag{1b}$$

$$D_S = \alpha_S - p_S + \gamma q_S. \tag{1c}$$

The demand for goods (1a) is linearly affected by (i) quality and price of goods and services in the conventional channel and (ii) quality and price of servitized goods in the servitized channel. The demand for servitized goods (1b) has the similar form. However, the demand for services (1c) is affected by its own price and quality because services in the conventional channel are assumed as supplementary, thereby the market for services can exist only when goods are purchased. α_{GS} is the market base for servitized goods, and the total market base for goods and servitized goods ($\alpha_G + \alpha_{GS}$) is assumed as 1 without loss of generality. We assume that α_G is larger than α_{GS} because the conventional channel has an advantage over the servitized channel by occupying the market in advance. This is reasonable because in general the servitized goods appear in the market only after the product achieves a certain degree of penetration rate in the traditional channel. γ stands for the quality sensitivity, i.e., the demand responsiveness to the quality difference between two channels or to service quality. Since price sensitivity is assumed as 1, γ can be also interpreted as the importance of quality compared to that of price.

The competing firms have convex cost functions in terms of the quality level. η_G, η_S, and η_{GS} are the quality cost coefficients that stand for the difficulty level of achieving the desired quality. Then the following profit functions are obtained.

$$\pi_G = D_G p_G - \frac{1}{2}\eta_G (q_G)^2$$

$$\pi_S = D_S p_S - \frac{1}{2}\eta_S (q_S)^2, \text{ and}$$

$$\pi_{GS} = D_{GS} p_{GS} - \frac{1}{2}\eta_{GS} (q_{GS})^2. \tag{2}$$

Table 1 summarizes terms used in the proposed model.

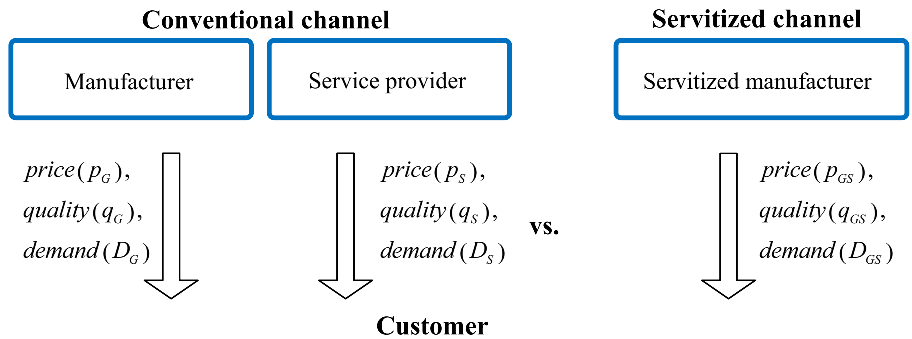

Fig. 1. Channel competition in Case 1.

3.1. Case 1: An independent manufacturer and a service provider

In Case 1, a manufacturer and a service provider exist as a separate entity in the conventional channel as depicted in Fig. 1.

In this case, an independent manufacturer and a service provider offer goods and services to customers by separately setting the optimal quality and price for goods and services. Likewise, the servitized firm provides the servitized goods under the optimal quality and price. To ensure profit maximization, each firms profit, π_G, π_S, and π_{GS} should possess the concavity conditions under the price and quality equilibrium. Since a function is concave if and only if all the non-zero principal minors have the same sign $(-1)^k$ where k is the number of variables, the following proposition can be offered:

Proposition 1. The firm's profit is strictly concave in price and quality if quality cost coefficient is sufficiently larger than quality sensitivity. More specifically, the manufacturer's profit, π_G is strictly concave in p_G and q_G if $\eta_G > \gamma^2/2$. Similarly, π_S is strictly concave in p_S and q_S if $\eta_S > \gamma^2/2$, and π_{GS} is strictly concave in p_{GS} and q_{GS} if $\eta_{GS} > \gamma^2/2$.

Proofs for the above proposition are provided in Appendix A. Proposition 1 shows that an optimal solution for the price and quality for each channel exists under some conditions.

If this model is solved through backward induction, the prices for each offering can be obtained.

$$p_G^* = \frac{\gamma\left(-2+\phi^2\right)(2q_G+\theta q_S)+\left(2\theta-4-\phi^2\theta\right)\alpha_G+2\phi(\gamma q_{GS}-\alpha_{GS})}{2\left(-4+\phi^2\right)}$$

$$p_S^* = \frac{(\gamma q_S+\theta\alpha_G)}{2}$$

$$p_{GS}^* = \frac{2\gamma\left(-2+\phi^2\right)q_{GS}+\gamma\phi(2q_G+\theta q_S)2q_G-\left(2+\theta^2\right)\phi\alpha_G-4\alpha_{GS}}{2\left(-4+\phi^2\right)} \quad (3)$$

From these equilibrium prices, we can validate that price for goods in the conventional channel is positively (negatively) influenced by the quality of the conventional goods (servitized goods). In addition, we can verify that higher prices in a channel can be charged as the market base for the channel increases. Taking back the stages, (3) will be inserted into (2). Then the following result for quality can be obtained. Under the concave conditions, the optimal price and quality levels can be found as below.

$$q_G^* = \frac{4\gamma^3\Phi_2^2\left(\phi\alpha_{GS}\Gamma_{2S}+\alpha_G\left(\Gamma_{2S}+\theta^2\Gamma_S(1+\Phi_2)\right)\right)-2\gamma\eta_{GS}\Phi_2\left((2\alpha_G+\phi\alpha_{GS})\Gamma_{2S}+\theta^2\alpha_G\Gamma_S\Phi_2\right)\Phi_4}{\Gamma_{2S}\left(4\gamma^4\Phi_2^2(1+\Phi_2)-2\gamma^2(\eta_G+\eta_{GS})\Phi_2^2\Phi_4+\eta_G\eta_{GS}\Phi_4^3\right)}$$

$$q_S^* = -\frac{\gamma\theta\alpha_G}{\Gamma_{2S}}$$

$$q_{GS}^* = \frac{4\gamma^3(\phi\alpha_G+\alpha_{GS})\Phi_2^2-2\gamma\left(2\alpha_{GS}\Gamma_{2S}+\phi\alpha_G\left(\theta^2\Gamma_S+\Gamma_{2S}\right)\right)\eta_G\Phi_2\Phi_4}{\Gamma_{2S}\left(4\gamma^4\Phi_2^2(1+\Phi_2)-2\gamma^2(\eta_G+\eta_{GS})\Phi_2^2\Phi_4+\eta_G\eta_{GS}\Phi_4^3\right)}, \quad (4)$$

where

$\Gamma_{2GS} = \gamma^2 - 2\eta_{GS}$, $\Gamma_{GS} = \gamma^2 - \eta_{GS}$, $\Gamma_{2S} = \gamma^2 - 2\eta_S$,
$\Gamma_S = \gamma^2 - \eta_S$, $\Gamma_{2G} = \gamma^2 - 2\eta_G$,
$\Gamma_G = \gamma^2 - \eta_G$, $\Phi_1 = \phi^2 - 1$, $\Phi_2 = \phi^2 - 2$, $\Phi_4 = \phi^2 - 4$

Taking back the stages, (4) will be inserted into (3). Then the optimal price below can be obtained.

$$p_G^* = \frac{\Phi_4\eta_G\left(\alpha_G\left(\Phi_4\eta_{GS}\left(\left(\theta^2\Phi_2+4\right)\eta_S-\gamma^2\left(\theta^2\Phi_2+2\right)\right)+2\gamma^2\Phi_2\left(\left(\theta^2\Phi_1+2\right)\Gamma_S-\gamma^2\right)\right)+\phi\alpha_{GS}\Gamma_{2S}(2\gamma^2\Phi_2-\Phi_4\eta_{GS})\right)}{\Gamma_{2S}\left(\Phi_4\eta_G\left(\Phi_4^2\eta_{GS}-2\gamma^2\Phi_2^2\right)+2\gamma^2\Phi_2^2(2\gamma^2\Phi_1-\Phi_4\eta_{GS})\right)}$$

$$p_S^* = -\frac{\theta\alpha_G\eta_S}{\Gamma_{2S}}$$

$$p_{GS}^* = \frac{\Phi_4\eta_{GS}\left(2\alpha_{GS}\Gamma_{2S}(\gamma^2\Phi_2-\Phi_4\eta_G)+\phi\alpha_G\left(2\gamma^2\Phi_2\Gamma_{2S}-\Phi_4\eta_G\left(\left(\theta^2+2\right)\Gamma_S-\gamma^2\right)\right)\right)}{\Gamma_{2S}\left(\Phi_4\eta_G\left(\Phi_4^2\eta_{GS}-2\gamma^2\Phi_2^2\right)+2\gamma^2\Phi_2^2(2\gamma^2\Phi_1-\Phi_4\eta_{GS})\right)} \quad (5)$$

The profits under the optimal quality and price for the conventional manufacturer and the servitized firm can be calculated with the above information. By comparing the two profits, we can obtain the conditions for achieving a competitive advantage as in the following proposition. Since the cost structure of competing firms is not a focus of this study, we assume that all the cost coefficients are identical, so $\eta = \eta_G = \eta_S = \eta_{GS}$ will be applied.

Proposition 2. There exist thresholds of both θ and ϕ such that π_{GS} is better off than π_G when (i) both θ and ϕ are larger than the thresholds, and (ii) $\alpha_{GS}\eta > \gamma^2/2$.

Propositions 2 shows the existence of thresholds of service dependency and channel substitutability where the servitized firm's profit is higher than the conventional manufacturer's profit. Under this condition, the manufacturer who is dependent on services has to consider changing its own goods provision structure to pursue the servitization strategy for higher profit. This result is in line with previous empirical findings in servitization literature that the service transition of manufacturers does not always guarantee higher profit (e.g., Visnjic Kastalli and Van Looy, 2013; Suarez et al., 2013; Schröter and Lay, 2014). Morever, if the market base for servitized goods expands up to the situation that α_{GS} is larger than α_G, π_{GS} is always better off than π_G under $\alpha_{GS}\eta > \gamma^2/2$. Therefore, if market condition changes, then the conventional channel participants may consider servitization to increase its profit.

We investigate the differences in the prices and qualities for the two channels by comparing the quality and price of the servitized channel and the combined quality and price of the conventional channel, respectively. The combined quality and price can be obtained using the service dependency parameter (θ). For example, the combined quality of goods and services in the conventional channel can be defined as $q_G+\theta q_S$. Under the equilibrium, the optimal quality of the servitized channel is always inferior to the combined quality of the conventional channel when service dependency and channel substitutability have their own extreme values. That is, if both parameters are either zero or one, the servitized firm does not need to provide higher quality compared to the conventional channel considering Proposition 2 because the servitized channel has a competitive advantage under high θ and ϕ values in spite of the lower quality. At all corners of substitutability and service dependency, the expected quality for the conventional channel can be dominant, but the near area for $\phi=1$and $\theta=1$is not beneficial for the conventional channel manager due to lower profit level. To overcome this disadvantage, the conventional channel should differentiate with their goods to induce less substitutability and should make supplementary services simpler to reduce service dependency. The relevant proof is available in the appendix.

3.2. Case 2: An integrated manufacturer and service provider

A manufacturer may integrate (or may be integrated by) a service provider in the conventional channel. In Case 2, the manufacturer and service provider exist as an integrated entity in the conventional channel as depicted in Fig. 2. However, the price and quality for the goods and services in the conventional channel are set separately by the integrated firm. It is worthwhile to note that this setting is defined as the servitization strategy in many empirical articles (e.g., Fang et al., 2008; Han et al., 2013; Suarez et al., 2013).

In this case, π_{G+S} is defined as the combined profit for the integrated manufacturer and service provider. As in Case 1, π_{G+S} and π_{GS} should also possess the concavity conditions under the price and quality equilibrium. Accordingly, the following proposition is offered:

Proposition 3. π_{G+S}, the profit for the integrated manufacturer and service provider, is strictly concave in p_G, q_G, p_S, and q_S. π_{GS}, the profit for the servitized manufacturer is strictly concave in p_{GS} and q_{GS} if $\eta_{GS}>\gamma^2/2$.

Propositions 3 shows that an optimal solution for the price and quality for each channel exists under some conditions. If this model is solved through backward induction, the equilibrium prices can be obtained as follows.

$$p_G^*=\frac{\left(-2+\phi^2\right)\left(-2\gamma q_G+\theta\left(-\gamma q_S+\theta\alpha_G\right)\right)+4\alpha_G+2\phi\left(\alpha_{GS}-\gamma q_{GS}\right)}{8-2\phi^2+\theta^2\left(-2+\phi^2\right)}$$

$$p_S^*=\frac{\left(-2+\phi^2\right)\left(\gamma\theta q_G+\gamma\theta^2 q_S-\theta\alpha_G\right)+\gamma\theta\phi q_{GS}+\left(4-\phi^2\right)\gamma q_S-\theta\phi\alpha_{GS}}{8-2\phi^2+\theta^2\left(-2+\phi^2\right)}$$

$$p_{GS}^*=\frac{\gamma\left(4-\theta^2+\left(-2+\theta^2\right)\phi^2\right)q_{GS}-2\gamma\phi q_G-\gamma\theta\phi q_S+2\phi\alpha_G+\left(4-\theta^2\right)\alpha_{GS}}{8-2\phi^2+\theta^2\left(-2+\phi^2\right)} \quad (6)$$

The optimal price and quality levels can be obtained for Case 2 similarly with Case 1 as explained in detail in Appendix B.

From these equilibrium prices and further results, it can be observed that an integrated firm (i.e., a manufacturer and service provider) in the conventional channel is always better off than the servitized firm if the base market size of the conventional channel is larger than that of the servitized channel. However, if the base market size of the servitized channel becomes larger than a certain threshold, the profit of the servitized firm will be higher than that of the integrated firm in the conventional channel. This observation shows that the manufacturer's adoption of the service may be a good strategy but not always. If α_G is smaller than α_{GS} (i.e., the market base for servitized goods becomes larger), the servitized channel has a competitive advantage over the other channel. Therefore, manufacturing firms should deploy appropriate service strategies based on several industry and firm characteristics (Cusumano et al., 2015).

3.3. Comparison of Case 1 and Case 2

The manufacturer in Case 1 may have two strategic paths for gaining a competitive advantage: (i) integrating a service provider as in Case 2 or (ii) integrating goods and services, i.e., servitization. To compare these two cases, we introduce subscripts 1 and 2 for Cases 1 and 2, respectively. For example, the price of servitized goods is represented by p_{GS1} and p_{GS2} for each case. Let the profit difference in Cases 1 and 2 defined as $\Delta\pi_1=\pi_{GS1}-\pi_{G1}$ and $\Delta\pi_2=\pi_{GS2}-(\pi_{G+S2})$, respectively, then the following proposition can be obtained:

Proposition 4. The higher service dependency and channel substitutability, the larger the profit advantage of the servitization strategy in Case 1 (an independent manufacturer and a service provider) comparing to Case 2 (an integrated manufacturer and service provider).

Proposition 4 means that, under high service dependency and channel substitutability, a servitized channel has a higher competitive advantage when there exist an independent manufacturer and a service provider in the conventional channel than when an integrated firm serves customers in the market. Therefore, a manufacturer with a low level of service provision is expected to benefit more from adopting servitization strategy when certain product- and market-level conditions are met. In addition to other moderating variables suggested by previous studies such as product innovation (Visnjic et al., 2016), product complexity (Bikfalvi et al., 2013), globalization (Myrthianos et al., 2014), and organizational design (Gebauer et al., 2010) among others, service

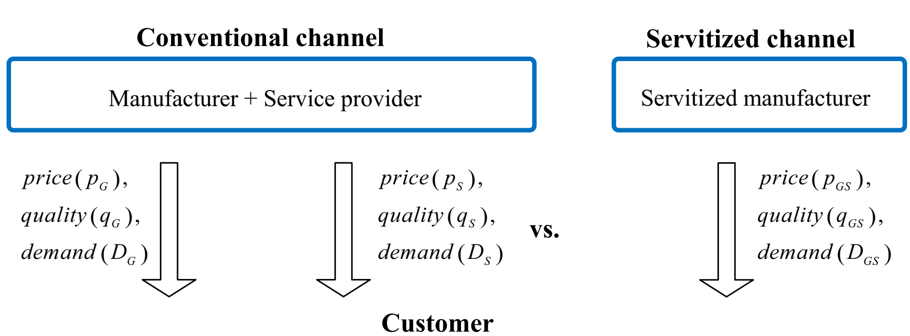

Fig. 2. Channel competition under an integrated manufacturer and service provider.

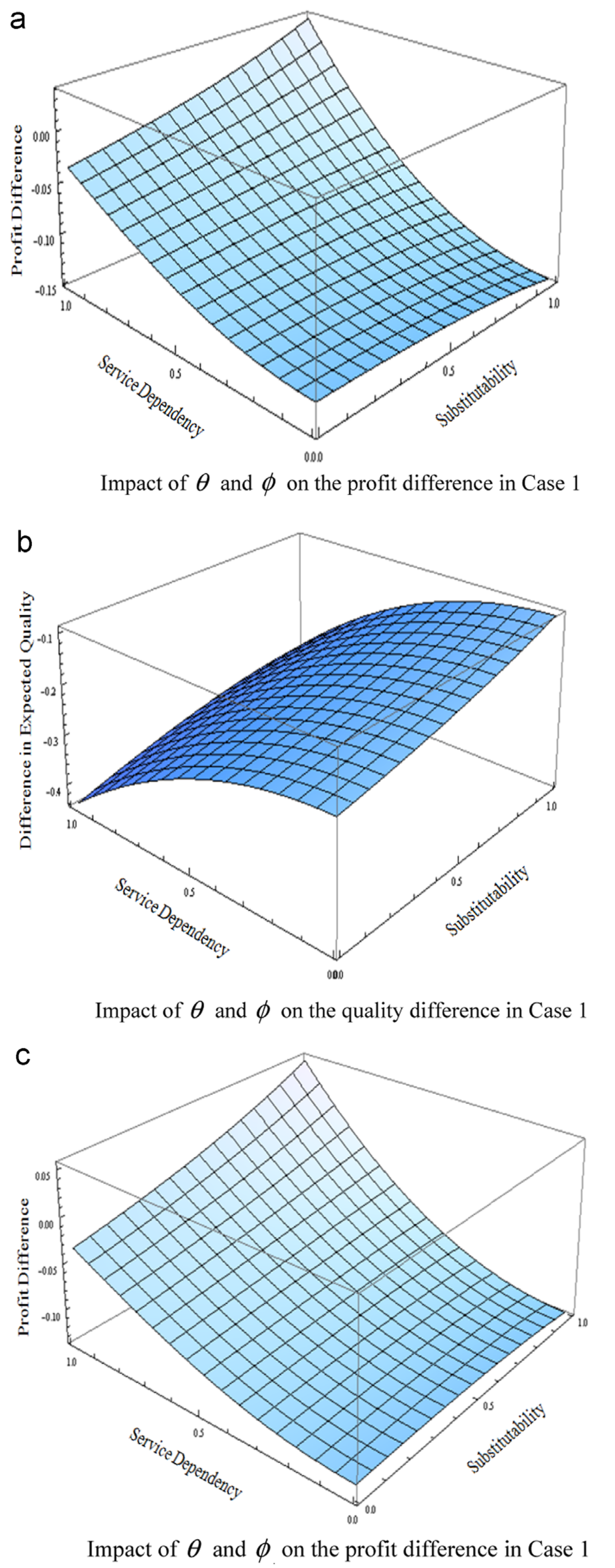

Fig. 3. (a) Impact of θ and ϕ on the profit difference in Case 1. (b) Impact of θ and ϕ on the quality difference in Case 1. (c) Impact of θ and ϕ on the profit difference in Case 1 with improved cost coefficient of the servitized channel.

dependency and channel substitutability are proved to play an important role in the relationship between servitization and firm performance.

There exists a relationship between quality cost coefficients and the threshold levels of service dependency and channel substitutability that make the servitization strategy more profitable. In other words, as η_{GS} decreases, a competitive advantage is obtained with less investment as in the following proposition:

Proposition 5. As the servitized firm improves its cost efficiency, the servitized firm has a competitive advantage on broader areas of service dependency and channel substitutability than a non-integrated manufacturer.

According to Proposition 5, the threshold level for service dependency and channel substitutability will be lessened if the servitized firm achieves cost efficiency. A lower threshold means that the servitized firm has higher competitiveness over the conventional channel. Thus, the servitized firm has an incentive to exert efforts to employ cost reduction tactics. If any investment is required for achieving cost reduction, managers should consider the trade-off between the investment and channel competitiveness. Multiple analytical and empirical studies also found that cost is an important moderator that may affect the effectiveness of servitization strategy (e.g., Zhen, 2012; Gebauer et al., 2005; Neely, 2008).

4. Numerical experiment

A numerical experiment is conducted to more clearly show the relationship between the model parameters and the profitability of the servitization strategy. Under certain numerical assumptions that ensure the concavity conditions for both cases[3], Fig. 3 shows the relationship between the two critical model parameters (i.e., service dependency and channel substitutability) and selected analytical results (i.e., profit and quality difference between the conventional channel and the servitized channel). Fig. 3a illustrates the impact of θ (service dependency) and ϕ (channel substitutability) on the profit difference in Case 1. As the service dependency increases, the profit difference also increases under higher substitutability. This means that the interaction affects the service and channel characteristics when their values are high enough. In other words, the channels should be more interchangeable and the services should be more dependable to make the servitization strategy more profitable.

Fig. 3b illustrates the impact of θ and ϕ on the expected quality difference in Case 1. As the service dependency decreases and the substitutability increases, the absolute difference in expected quality decreases. This means that more substitutable channels and higher service requirements make less difference in the expected quality between the conventional and the servitized channel. Thus, in Fig. 3a and b, a contrary effect on the profit and quality difference of service dependency can be found. For greater profit, the service should be more dependable, but for less difference in quality, the goods should be less dependable on services. In addition, Fig. 3c shows the revised result of Fig. 3a when the η_{GS} value is changed from 0.6 to 0.5, i.e., when cost efficiency is improved. It can be noted that under improved cost efficiency, the servitized firm obtain a competitive advantage in a broader areas of key parameters.

Fig. 4 illustrates the impact of α_{GS} on the profit difference in Case 2 under five different conditions of θ (service dependency) and ϕ (channel substitutability). Since higher base market size for the servitized channel implies that the servitized manufacturer can more easily secure a stable and sizable demand, the profit increase

[3] We set $\alpha_G = 0.7$, $\alpha_{GS} = 0.3$, $\eta_G = 0.6$, $\eta_S = 0.6$, $\eta_{GS} = 0.6$, and $\gamma = 0.5$ in this numerical experiment.

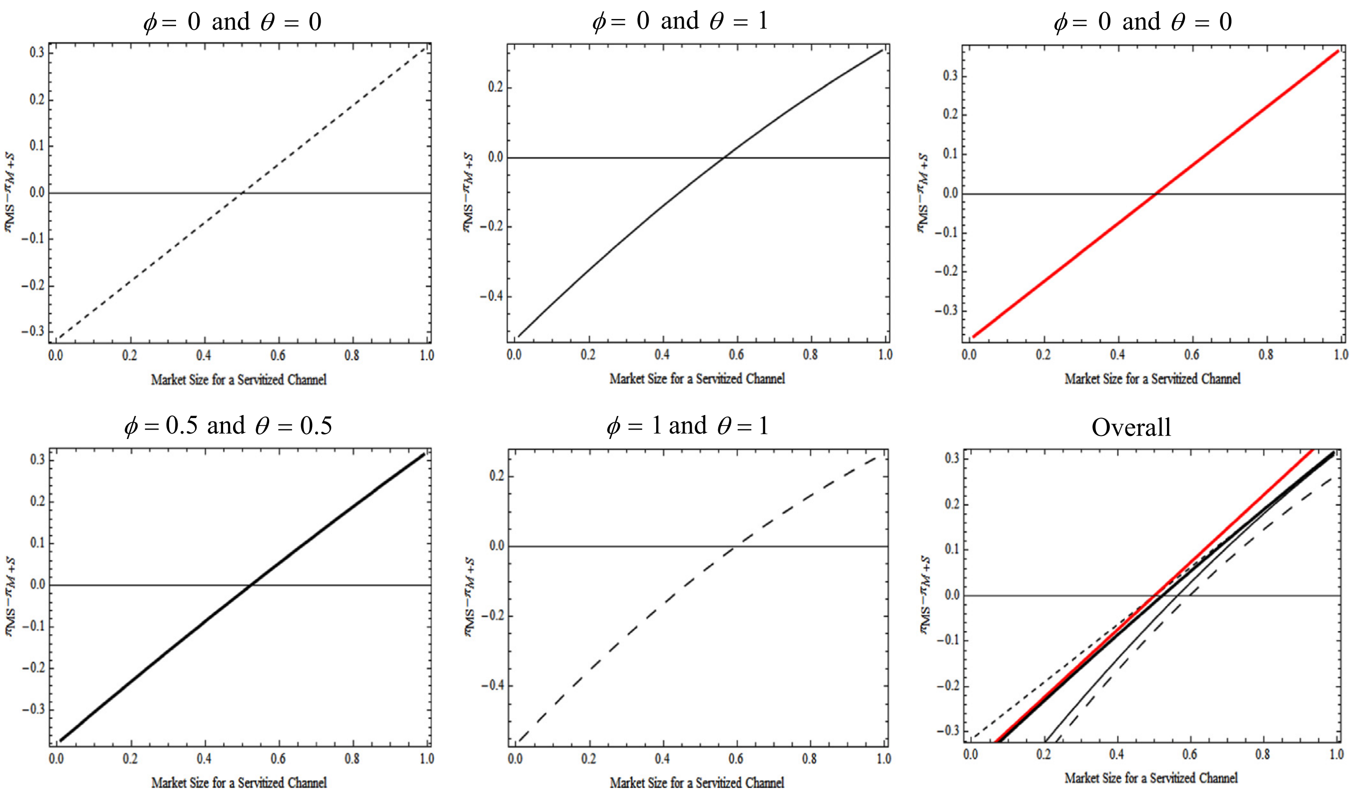

Fig. 4. Impact of α_{GS} on the profit difference in Case 2.

from servitization becomes larger with the base market size. Therefore, the servitized firm should attempt to enhance the market base through other activities such as promoting the value of the servitized products and increasing consumers' accessibility to the servitized channel.

5. Conclusion

The proposed model examines competition between a conventional channel where physical goods and services are separately provided and a newly introduced channel where servitized products are offered by a single firm while service dependency and channel substitutability change. The impacts of the two variables on the channel performance and relationship are explored. The results of our study enable practitioners to identify the strategic implications of their own service composition and channel characteristics with respect to the servitization strategy. This paper has a twofold contribution. First, it presents an analytical model of channel competition considering a product-level servitization strategy, which is the first attempt in the literature to the best of our knowledge. In the servitization literature, empirical research has been done in many aspects, but an analytical comparative approach has not been employed. Second, practitioners and researchers can find some critical conditions that make servitization strategy a viable one. According to the magnitude of service dependency and channel substitutability, managers can determine an appropriate servitization strategy to maximize the firm's profit. Under high channel substitutability for instances, managers in a manufacturer should consider servitization to increase the firm's profit since customers can more easily realize the value of servitized products and switch to the newly offered servitized product.

This research has several limitations that suggest future research agenda. First, we do not consider other characteristics of services except price and quality. However, there exist various aspects of services in reality that may provide interesting implications on the servitization strategy. Identifying such characteristics of services and analyzing their implications would be a fruitful area to more thoroughly understand the servitization phenomenon. Second, it is assumed that the market base for goods is larger than that of servitized products, and that the sum of the two is fixed in this study. However, these assumptions can be relaxed to incorporate any endogeneity in reality. For example, more manufacturers' strategic moves to servitization may change the size of the market base for the conventional and/or the servitized channel. Examining this issue will be also an interesting research avenue in future studies. Third, since the current study does not incorporate any cost structure of goods production and service provision, future research can also investigate whether a firm- or industry-specific cost structure would generate different implications for the servitization strategy.

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Appendix A. Proofs of Propositions

Proof of Proposition 1 :

The Hessian matrix for a manufacturer is:

$$H_G = \begin{pmatrix} -2 & \gamma \\ \gamma & -\eta_G \end{pmatrix} \tag{A1}$$

It is straightforward that the first principal minor has a minus sign as can be seen in -2 and $-\eta_G$.

Therefore, π_G is strictly concave if $2\eta_G - \gamma^2 > 0 \Rightarrow \eta_G > \gamma^2/2$.

Hessians for a service provider and a servitized firm are as below.

$$H_S = \begin{pmatrix} -2 & \gamma \\ \gamma & -\eta_S \end{pmatrix}, \ H_{GS} = \begin{pmatrix} -2 & \gamma \\ \gamma & -\eta_{GS} \end{pmatrix} \tag{A1′}$$

As based on the above statements, π_S is strictly concave if $2\eta_S - \gamma^2 > 0 \Rightarrow \eta_S > \gamma^2/2$ and π_{GS} is strictly concave if $2\eta_{GS} - \gamma^2 > 0 \Rightarrow \eta_{GS} > \gamma^2/2$.

Proof of Proposition 2 :

To show the existence of threshold levels for service dependency (θ) and channel substitutability (ϕ), we investigate the change of profit difference ($\pi_{GS} - \pi_G$) with respect to θ and ϕ.

First, we check the profit difference when $\theta = \phi = 0$.

In this case, $\pi_{GS} - \pi_G = \frac{(1-2\alpha_{GS})\eta}{2(\gamma^2 - 2\eta)}$ has a negative sign because it is assumed that all quality cost coefficients are same, and α_G is larger than α_{GS}. Therefore, π_{GS} is less than π_G.

Second, we check the profit difference when $\theta = \phi = 1$.

The value of profit difference $\pi_{GS} - \pi_G = \frac{(2\gamma^2 - 9\eta)(\gamma^2 - 2\alpha_{GS}\eta)}{3(4\gamma^2 - 9\eta)(\gamma^2 - 2\eta)}$ has a positive sign when $\gamma^2 - 2\alpha_{GS}\eta < 0$ because other components $\gamma^2 - 2\eta$, $4\gamma^2 - 9\eta$ and $2\gamma^2 - 9\eta$ are negative under the concavity condition. In this case, π_{GS} is larger than π_G.

Therefore, we can conclude that there exist thresholds of $\tilde{\phi}$, $\tilde{\theta}$ such that π_{GS} is larger than π_G, when $0 < \tilde{\phi} < 1$ and $0 < \tilde{\theta} < 1$.

Proof of the expected quality difference in Case 1

i) if $\phi = 0$ and $\theta = 0$

The quality difference for two channels, $\Delta q^* = q^*_{GS} - (q^*_G + \theta q^*_S)$, is $\Delta q^* = \frac{\gamma(1-2\alpha_{GS})}{(\gamma^2 - 2\eta)}$, and this is less than zero because $1 - 2\alpha_{GS} > 0$ and $\gamma^2 - 2\eta < 0$.

ii) if $\phi = 1$ and $\theta = 1$

$\Delta q^* = \frac{2\gamma(-9+8\alpha_{GS})}{4\gamma^2 - 9\eta} - \frac{5\gamma(-1+\alpha_{GS})}{\gamma^2 - 2\eta}$ is less than zero because it is less than $\frac{2\gamma(-9+8\alpha_{GS})}{4\gamma^2 - 8\eta} - \frac{5\gamma(-1+\alpha_{GS})}{\gamma^2 - 2\eta} = \frac{\gamma(1-2\alpha_{GS})}{2(\gamma^2 - 2\eta)} < 0$.

iii) if $\phi = 0$ and $\theta = 1$

$\Delta q^* = \frac{\gamma^3(1-2\alpha_{GS}) + \gamma\eta(-3+5\alpha_{GS})}{(\gamma^2 - 2\eta)^2}$ is less than zero because it is less than $\frac{\gamma^3(1-2\alpha_{GS}) - 3\gamma\eta(1-2\alpha_{GS})}{(\gamma^2 - 2\eta)^2} = \frac{\gamma(\gamma^2 - 2\eta)(1-2\alpha_{GS})}{(\gamma^2 - 2\eta)^2} < 0$.

iv) if $\phi = 1$ and $\theta = 0$

it is straightforward that $\Delta q^* = \frac{2\gamma(1-2\alpha_{GS})}{4\gamma^2 - 9\eta}$ is less than zero.

Proof of Proposition 3 :

The Hessian matrix for the integrated manufacturer is as below.

$$H = \begin{pmatrix} -2 & \gamma & -\theta & \gamma\theta \\ \gamma & -\eta_G & 0 & 0 \\ -\theta & 0 & -2 & \gamma \\ \gamma\theta & 0 & \gamma & -\eta_S \end{pmatrix} \tag{A2}$$

π_{G+S} is concave if the following conditions are met.

i) 1st principal minors < 0, which implies

$$-2 < 0, \ -\eta_G < 0, \ -2 < 0, \ -\eta_S < 0, \ -\eta_S < 0$$

ii) 2nd principal minors > 0, which implies

$$2\eta_S - \gamma^2 > 0, \ \eta_G\eta_S > 0, \ 2\eta_G > 0, \ 2\eta_S - \theta^2\gamma^2 > 0, \ 4 - \theta^2 > 0, \ 2\eta_G - \gamma^2 > 0$$

iii) 3rd principal minors < 0, which implies

$$\gamma^2\eta_G - 2\eta_G\eta_S < 0, \ 2\gamma^2 - 4\eta_S + \theta^2\eta_S < 0, \ -\gamma^2\theta^2\eta_G + \gamma^2\eta_S - 2\eta_G\eta_S < 0, \ 2\gamma^2 - 4\eta_G + \theta^2\eta_G < 0$$

iv) 4th principal minors >0, which implies

$$\gamma^4-2\gamma^2\eta_G-2\gamma^2\eta_S+4\eta_G\eta_S-\theta^2\eta_G\eta_S>0$$

The concave condition for π_{GS} is identical with that in Case 1.

Proof of Proposition 4:
When the profit difference is defined as $\Delta\pi_1=\pi_{GS1}-\pi_{G1}$ and $\Delta\pi_2=\pi_{GS2}-(\pi_{G+S2})$, the following results are obtained.

v) if $\phi=0$ and $\theta=0$
$\Delta\pi_1-\Delta\pi_2=0$

vi) if $\phi=1$ and $\theta=1$

From the proof of Proposition 3 with $\theta=\phi=1$, the following conditions should be considered.

a) $2\gamma^2-4\eta_S+\theta^2\eta_S<0\Rightarrow\gamma^2<\frac{3}{2}\eta$
b) $2\gamma^2-4\eta_G+\theta^2\eta_G<0\Rightarrow\gamma^2<\frac{3}{2}\eta$
c) $\gamma^4-2\gamma^2\eta_G-2\gamma^2\eta_S+4\eta_G\eta_S-\theta^2\eta_G\eta_S>0\Rightarrow$ $(\gamma^2-3\eta)(\gamma^2-\eta)>0\Rightarrow\gamma^2>3\eta$ or $\gamma^2<\eta$
d) $\gamma^2<2\eta$

The binding condition becomes $\gamma^2<\eta$. For simplicity, let $\gamma^2=a\eta$ $(0<a<1)$, then
$\Delta\pi_1-\Delta\pi_2$ under $\theta=\phi=1$ becomes

$$\Delta\pi_1-\Delta\pi_2=\frac{(-9+2a)(a-2\alpha_{GS})}{54-51a+12a^2}+\frac{\left\{\begin{array}{l}2(5625+a(-7075+a(1650+(505-141a)a)))\\+5\alpha_{GS}\left(\begin{array}{l}-5250+2a(4285+a(-2145+329a))\\-5(-300+49a(11+(-6+a)a))\alpha_{GS}\end{array}\right)\end{array}\right\}}{50(25+7(-4+a)a)^2}>0$$

Because $\Delta\pi_1-\Delta\pi_2$ under $\theta=\phi=1$ is positive at all times and $\Delta\pi_1-\Delta\pi_2$ is zero under $\theta=\phi=0$, the proposition 4 can be validated.
Proof of Proposition 5 :

The servitized firm in Case 1 is better off when $\gamma^2-2\alpha_{GS}\eta_{GS}<0$ and $\gamma^2-2\eta_{GS}<0$. Further, we assume that α_{GS} for the market base for servitized goods is less than α_G for the market base for goods $(0<\alpha_{GS}<0.5)$. In this regard, $2\alpha_{GS}$ is less than 1. Accordingly, the binding condition becomes $\gamma^2=a\eta$ $(0<a<1)$.

$\Delta\pi_1(\eta_{GS})=\pi_{GS1}(\eta_{GS})-\pi_{G1}(\eta_{GS})$ is larger than $\Delta\pi_1(b\eta_{GS})=\pi_{GS1}(b\eta_{GS})-\pi_{G1}(b\eta_{GS})$ under $\theta=\phi=1$ when $b>1$ because,

$$\Delta\pi_1(\eta_{GS})-\Delta\pi_1(b\eta_{GS})$$
$$=2a(-1+b)(9+2(-5+a)a+3\alpha_{GS})\times\frac{\left(\begin{array}{l}4(-2+a)a(-9+2a)\\ \\-3(81+10(-6+a)a)b+3(9-4a)b\alpha_{GS}\end{array}\right)}{9(-2+a)^2(-9+4a)(9b-2a(1+b))^2}>0.$$

That is, the profit difference is reduced if the quality cost coefficient becomes larger. Further, $\frac{\partial(\Delta\pi_1(b\eta_{GS}))}{\partial b}$ has a negative sign, because $\frac{\partial(\pi_{GS1}(b\eta_{GS}))}{\partial b}$ has a negative sign and $\frac{\partial(\pi_{G1}(b\eta_{GS}))}{\partial b}$ has a positive sign under the condition $0<\alpha_{GS}<0.5$, $0<a<1$ and $b>1$.

Therefore, $\Delta\pi_1(\eta_{GS})=\pi_{GS1}(\eta_{GS})-\pi_{G1}(\eta_{GS})$ overwhelms $\Delta\pi_1(b\eta_{GS})=\pi_{GS1}(b\eta_{GS})-\pi_{G1}(b\eta_{GS})$ under the given condition. That is why the servitized firm with better cost efficiency outperforms the manufacturers under the broader areas of service dependency and channel substitutability.

Appendix B. Optimal price and quality levels in Case 2

The optimal price and quality levels in Case 2 can described as below.

$$q_G^*=\frac{\left(\begin{array}{l}\gamma\Theta_4\Phi_2\phi\alpha_{GS}(2\gamma^2(\Theta_2\Phi_1+2)-(\Theta_2\Phi_2+4)\eta_{GS})\Gamma_{2S}\\+\alpha_G\left((2\gamma^2(\Theta_2\Phi_1+2))\left(\Gamma_{2S}-\theta^2\Phi_1\Gamma_S\right)-(\Theta_2\Phi_2+4)\eta_{GS}\left(2\Gamma_{2S}-\theta^2\Phi_2\Gamma_S\right)\right)\end{array}\right)}{\left(\begin{array}{l}\gamma\Theta_4\Phi_2(2\gamma^2\Phi_1(\Theta_2\Phi_1+2)-\Phi_2(\Theta_2\Phi_2+4)\eta_{GS})\Gamma_{2S}\\+\eta_G\left(\begin{array}{l}2\gamma^4\left(-2\Phi_2+\theta^2\Phi_1\right)\left(\theta^2(3\Phi_2+2)+2\Phi_2\Phi_4\right)\\+\left(2\Phi_4-\theta^2\Phi_2\right)\left(2\gamma^2\left(\Phi_4^2+2\theta^2\Phi_2\right)\eta_{GS}+\left(2\gamma^2(\Theta_2\Phi_1+2)^2-(\Theta_2\Phi_2+4)^2\eta_{GS}\right)\eta_S\right)\end{array}\right)\end{array}\right)} \quad \text{(B1)}$$

$$q_S^* = \frac{-\left(\gamma\theta\left(\begin{array}{l}(\Theta_4\phi\Phi_2\alpha_{GS}\eta_G)(2\gamma^2(\Theta_2\Phi_1+2)-(\Theta_2\Phi_2+4)\eta_{GS})\\ +\alpha_G\left(\begin{array}{l}\left(2\gamma^4\Theta_4\Phi_2\Phi_1\left(\theta^2\Phi_1-2\Phi_2\right)+2\gamma^2\left(\theta^2\Phi_1-2\Phi_2\right)\begin{pmatrix}2\Phi_2(\Phi_4-2)+\theta^4\Phi_2\Phi_1\\ -2\theta^2\left(7-8\phi^2+2\phi^4\right)\end{pmatrix}\eta_G\right)\\ +\left(2\Phi_4-\theta^2\Phi_2\right)\left(\gamma^2\Theta_4\Phi_2^2+\begin{pmatrix}\theta^4\Phi_2^2+\theta^2\left(-28+22\phi^2-4\phi^4\right)\\ +2\left(24-12\phi^2+\phi^4\right)\end{pmatrix}\eta_G\right)\eta_{GS}\end{array}\right)\end{array}\right)\right)}{\left(\begin{array}{l}\gamma\Theta_4\Phi_2(2\gamma^2\Phi_1(\Theta_2\Phi_1+2)-\Phi_2(\Theta_2\Phi_2+4)\eta_{GS})\Gamma_{2S}\\ +\eta_G\left(\begin{array}{l}2\gamma^4\left(-2\Phi_2+\theta^2\Phi_1\right)\left(\theta^2(3\Phi_2+2)+2\Phi_2\Phi_4\right)\\ +\left(2\Phi_4-\theta^2\Phi_2\right)\left(2\gamma^2\left(\Phi_4^2+2\theta^2\Phi_2\right)\eta_{GS}+\left(2\gamma^2(\Theta_2\Phi_1+2)^2-(\Theta_2\Phi_2+4)^2\eta_{GS}\right)\eta_S\right)\end{array}\right)\end{array}\right)}$$

$$q_{GS}^* = \frac{\left(2\gamma\left(\theta^2\Phi_1-2\Phi_2\right)\left(\begin{array}{l}\phi\alpha_G\left(\gamma^2\Theta_4\Phi_2\Gamma_{2S}+\eta_G\left(\gamma^2\left(2\Phi_4+2\theta^2\Phi_3-\theta^4\Phi_2\right)+2(\Theta_2\Phi_2+4)\eta_S\right)\right)\\ +\Theta_4\alpha_{GS}(\gamma^2\Phi_2\Gamma_{2S}-\eta_G(\gamma^2\Phi_4+(\Theta_2\Phi_2+4)\eta_S))\end{array}\right)\right)}{\left(\begin{array}{l}\gamma\Theta_4\Phi_2(2\gamma^2\Phi_1(\Theta_2\Phi_1+2)-\Phi_2(\Theta_2\Phi_2+4)\eta_{GS})\Gamma_{2S}\\ +\eta_G\left(\begin{array}{l}2\gamma^4\left(-2\Phi_2+\theta^2\Phi_1\right)\left(\theta^2(3\Phi_2+2)+2\Phi_2\Phi_4\right)\\ +\left(2\Phi_4-\theta^2\Phi_2\right)\left(2\gamma^2\left(\Phi_4^2+2\theta^2\Phi_2\right)\eta_{GS}+\left(2\gamma^2(\Theta_2\Phi_1+2)^2-(\Theta_2\Phi_2+4)^2\eta_{GS}\right)\eta_S\right)\end{array}\right)\end{array}\right)}$$

$$p_G^* = \frac{-\left(\left(\theta^2\Phi_2-2\Phi_4\right)\eta_G\left(\begin{array}{l}\phi\alpha_{GS}(2\gamma^2(\Theta_2\Phi_1+2)-(\Theta_2\Phi_2+4)\eta_{GS})\Gamma_{2S}\\ +\alpha_G\begin{pmatrix}(2\gamma^2(\Theta_2\Phi_1+2))\left(\Gamma_{2S}-\theta^2\Phi_1\Gamma_S\right)\\ -(\Theta_2\Phi_2+4)\eta_{GS}\left(2\Gamma_{2S}-\theta^2\Phi_2\Gamma_S\right)\end{pmatrix}\end{array}\right)\right)}{\left(\begin{array}{l}\gamma\Theta_4\Phi_2(2\gamma^2\Phi_1(\Theta_2\Phi_1+2)-\Phi_2(\Theta_2\Phi_2+4)\eta_{GS})\Gamma_{2S}\\ +\eta_G\left(\begin{array}{l}2\gamma^4\left(-2\Phi_2+\theta^2\Phi_1\right)\left(\theta^2(3\Phi_2+2)+2\Phi_2\Phi_4\right)\\ +\left(2\Phi_4-\theta^2\Phi_2\right)\left(2\gamma^2\left(\Phi_4^2+2\theta^2\Phi_2\right)\eta_{GS}+\left(2\gamma^2(\Theta_2\Phi_1+2)^2-(\Theta_2\Phi_2+4)^2\eta_{GS}\right)\eta_S\right)\end{array}\right)\end{array}\right)} \quad \text{(B2)}$$

$$p_S^* = \frac{-\left(\theta\left(\phi\alpha_{GS}\eta_G\left(\begin{array}{l}(2\gamma^2(\Theta_2\Phi_1+2)-(\Theta_2\Phi_2+4)\eta_{GS})(\gamma^2(\Theta_3\Phi_2+2)-(\Theta_2\Phi_2+4)\eta_S)\\ +\alpha_G\left(\begin{array}{l}\left(\begin{array}{l}2\gamma^4\Theta_4\Phi_2\Phi_1\left(\theta^2\Phi_1-2\Phi_2\right)\\ +2\gamma^2\left(\theta^2\Phi_1-2\Phi_2\right)\begin{pmatrix}2\Phi_2(\Phi_4-2)+\theta^4\Phi_2\Phi_1\\ -2\theta^2\left(7-8\phi^2+2\phi^4\right)\end{pmatrix}\eta_G\end{array}\right)\\ +\left(2\Phi_4-\theta^2\Phi_2\right)\left(\gamma^2\Theta_4\Phi_2^2+\begin{pmatrix}\theta^4\Phi_2^2+\theta^2\left(-28+22\phi^2-4\phi^4\right)\\ +2\left(24-12\phi^2+\phi^4\right)\end{pmatrix}\eta_G\right)\eta_{GS}\end{array}\right)\end{array}\right)\right)\right)}{\left(\begin{array}{l}\gamma\Theta_4\Phi_2(2\gamma^2\Phi_1(\Theta_2\Phi_1+2)-\Phi_2(\Theta_2\Phi_2+4)\eta_{GS})\Gamma_{2S}\\ +\eta_G\left(\begin{array}{l}2\gamma^4\left(-2\Phi_2+\theta^2\Phi_1\right)\left(\theta^2(3\Phi_2+2)+2\Phi_2\Phi_4\right)\\ +\left(2\Phi_4-\theta^2\Phi_2\right)\left(2\gamma^2\left(\Phi_4^2+2\theta^2\Phi_2\right)\eta_{GS}+\left(2\gamma^2(\Theta_2\Phi_1+2)^2-(\Theta_2\Phi_2+4)^2\eta_{GS}\right)\eta_S\right)\end{array}\right)\end{array}\right)}$$

$$p_{GS}^* = \frac{\left(\eta_{GS}\left(\theta^2\Phi_2-2\Phi_4\right)\left(\begin{array}{l}\phi\alpha_G\left(\gamma^2\Theta_4\Phi_2\Gamma_{2S}+\eta_G\left(\gamma^2\left(2\Phi_4+2\theta^2\Phi_3-\theta^4\Phi_2\right)+2(\Theta_2\Phi_2+4)\eta_S\right)\right)\\ +\Theta_4\alpha_{GS}(\gamma^2\Phi_2\Gamma_{2S}-\eta_G(\gamma^2\Phi_4+(\Theta_2\Phi_2+4)\eta_S))\end{array}\right)\right)}{\left(\begin{array}{l}\gamma\Theta_4\Phi_2(2\gamma^2\Phi_1(\Theta_2\Phi_1+2)-\Phi_2(\Theta_2\Phi_2+4)\eta_{GS})\Gamma_{2S}\\ +\eta_G\left(\begin{array}{l}2\gamma^4\left(-2\Phi_2+\theta^2\Phi_1\right)\left(\theta^2(3\Phi_2+2)+2\Phi_2\Phi_4\right)\\ +\left(2\Phi_4-\theta^2\Phi_2\right)\left(2\gamma^2\left(\Phi_4^2+2\theta^2\Phi_2\right)\eta_{GS}+\left(2\gamma^2(\Theta_2\Phi_1+2)^2-(\Theta_2\Phi_2+4)^2\eta_{GS}\right)\eta_S\right)\end{array}\right)\end{array}\right)}$$

where,

$\Gamma_{2GS}=\gamma^2-2\eta_{GS},\ \Gamma_{GS}=\gamma^2-\eta_{GS},\ \Gamma_{2S}=\gamma^2-2\eta_S,\ \Gamma_S=\gamma^2-\eta_S,$
$\Gamma_{2G}=\gamma^2-2\eta_G,$
$\Gamma_G=\gamma^2-\eta_G,\ \Phi_1=\phi^2-1, \Phi_2=\phi^2-2,\ , \Phi_3=\phi^2-3,$
$\Phi_4=\phi^2-4,$
$\Theta_4=\theta^2-4,\ \Theta_2=\theta^2-2$

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