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JOINT PRICING, SERVICES AND QUALITY DECISIONS IN A DUAL-CHANNEL SUPPLY CHAIN

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Abstract. With the rapid development of the Internet, many manufacturers nowadays are increasingly adopting a dual-channel to sell their products, *i.e.*, the traditional retail channel and online direct channel. In this paper, we focus on retail service, manufacturer's direct service and quality effort, and present an analytical framework to examine the optimal decisions in dual-channel supply chain between the manufacturer and the retailer. Considering the efficacy of different supply chain structures, centralized and decentralized models are established. By using the backwards induction and the two-stage optimization technique in Stackelberg game, the corresponding analytical equilibrium solutions are obtained. Our analysis shows that the degree of customer loyalty to the direct channel strongly influences the manufacturer's and the retailer's services and quality strategies in the decentralized dual-channel supply chain, but not in the centralized model. Our results also point out that compared to centralized model, for any given selling price, the ratio of profit margins of selling one unit in the direct and retail channels determines the retailer's service strategy; and the manufacturer will raise the level of direct channel service, but put less effort on quality improvement in the decentralized model. Finally, numerical examples present the contrasting view that disparate interests within a dual-channel supply chain can actually realize improving outcomes.

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1. Introduction

The rapid development of information technology has not only led to an increasing number of people shopping directly online, but also led many manufacturers to complement their existing physical retail channels with a direct channel, which provides them with an opportunity to serve more customers who would otherwise have no intention to buy the manufacturers' products [14]. Many manufacturers−such as Hewlett & Packard, Lenovo, Compaq, Sony, Panasonic, Mattel, Pioneer Electronics, Cisco System, and Estee Lauder−sell products through their direct channels [2, 16, 34].

Although the Internet has become a significant direct channel, brick-and-mortar stores continue to play an important role in the market. On one hand, in many cases, service in the retail channel is a critical factor in promoting a product. Customers who want to buy may examine the product in the physical store. On the other hand, retailer needs to improve his retail services in order to survive [20]. Retail stores can stimulate demand

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by mailing advertisements, providing attractive shelf space, offering trial samples, and educating customers on how to use the product [27]. So, retail service plays a strategic role in a dual-channel competitive market.

Customer acceptance of the direct channel is different from that of conventional retail channel due to the quality of website interactions with the e-retailer, delivery of the product, uncertainty about obtaining the correct item, etc [38]. Empirical studies have shown that service quality [7, 28] is a major factor contributing to customer acceptance of the direct channel. If the manufacturer provides nice services in the direct channel, it would lead to increases in costs and reductions in profit margins; conversely, a terrible service would reduce customers' acceptance and loyalty to the direct channel. So, the decision on the level of manufacturer services in the direct channel is very important for dual-channel management. Moreover, quality is also one of the main components for their existence in the market. the manufacturer invests in technology and management to improve product quality; a larger investment in technology improves the quality of the product which results in an increased market potential (demand) for the product. However, the quality-improvement costs are directly incurred by the manufacturer only. As such, the manufacturer may charge a higher wholesale price in order to recuperate these costs [11]. Therefore, the decision on the quality effort invested by the manufacturer is very important for dual-channel management.

In this paper, we take all these issues into consideration and present an analytical framework for selling price, quality effort, manufacturer services, and retail services decisions in a centralized and a decentralized dual-channel supply chain, provide a decision making aid for the manufacturer and the retailer, and analyze the impact of customer loyalty to the direct channel on the manufacturer's and retailer's optimal decisions. In particular, our study addresses the following questions: (1) What are the optimal pricing, efforts decisions and profits in different models? (2) What is the influence of customer loyalty on dual-channel strategies? and (3) Through numerical study, which channel power structure is the best from point of total profits? We consider two fundamentally distinct scenarios: (a) centralized dual-channel supply chain, where all members of the supply chain are managed by a dominant decision maker whose objective is to maximize the total expected profit of the supply chain, and (b) decentralized dual-channel supply chain, where the manufacturer is Stackelberg leader, the retailer is follower.

Compare the paper with existing literature, there are two remarkable differences. First, lots of articles in the literature on dual-channel supply chain have considered retail service decision, manufacturer's direct service decision, or quality effort decision separately or combination of the two. To the best of our knowledge, this is the first to study price, quality, and services decisions simultaneously in a dual-channel supply chain under different channel structures. Second, few of them consider consistent pricing decision. Again, this assumption relates to the omni-channel retailing which is making a splash in China and also flourishing globally as an innovative business mode [19]. Moreover, service competition and product quality are more important issues in the dual-channel supply chain.

The remainder of this paper is organized as follows. In Section 2, the literature review is described. Section 3 introduces the notations, assumptions and the model. The theoretical results and comparisons of these results are presented in Section 4. We illustrate some managerial insights through numerical studies in Section 5. Section 6 gives conclusions and directions for future research.

2. Literature review

There are two streams of literature closely related to our study: services and quality effort. We next review each stream and position our paper accordingly.

2.1. Service decisions

By reviewing the previous research on service decisions, there can be mainly divided into two types about pricing problems: a supply chain with retailer's service and a supply chain with manufacturer's service [36].

Retail services have significant effects on customers'channel choice, demand and loyalty [39]. An increasing number of retailers incorporate their services into their operations to attract customers to their stores and compete with their rivals. Therefore, it is an interesting phenomenon to motivate retailers to provide and improve their retail service, including presale service (technical service, counseling service, product advertising, etc.), in-sale service (on-time product delivery, etc.) and after sale service (subsequent tracking service, enjoy all-around technical support and counseling all the time, etc.) [35].

For example, He *et al.* [12] investigated the issue of channel coordination for a supply chain facing stochastic demand that is sensitive to both sales effort and retail price. Zhao and Wang [41] studied the pricing and retail service decisions of a product in a supply chain with one manufacturer and two retailers. It was assumed that the supply chain is operated in fuzzy uncertainty environments. However, the development of the Internet and e-commerce created online stores and transformed sales channels from single to two or more channels. Tsay and Agrawal [34] developed a service competition model and demonstrated both supply chain players can mutually benefit from adding a direct channel. Chen *et al.* [2] studied a manufacturer's problem of managing its direct online sales channel together with an independently owned bricks-and-mortar retail channel, when the channels competed against each other in terms of service. Dumrongsiri *et al.* [8] modeled a supply chain with direct and retail channels, and then analyzed strategic interactions between the manufacturer and the retailer with a price and service quality sensitive demand. Yan and Pei [39] developed a framework to study the strategic roles of the retail services in a dual-channel supply chain. Their results indicated that the channel competition can effectively motivate the traditional retailer to improve its services. Dan *et al.* [6] examined the optimal decisions on retail services and prices in a centralized and a decentralized dual-channel supply chain using the two-stage optimization technique and Stackelberg game, and evaluated the impacts of retail services and the degree of customer loyalty to the retail channel on the manufacturer and retailer's pricing behaviors. Wang *et al.* [36] investigated the pricing and service decisions of complementary products in a dual-channel supply chain which consists of two manufacturers and one common retailer. Pu *et al.* [27] considered the effects of free riding on sales effort in a dual-channel supply chain consisting of one manufacturer and one offline store.

There is scant literature addressing the decision on the services of the direct channel and its impact on the manufacturer's and retailer's pricing decisions. Such service include: the installation of the product, maintenance, logistic information and other online services, etc. To fill this gap, Goffin [10] described an exploratory investigation of the distribution channels and customer support strategies of five manufacturing businesses, using case study methodology. Hua *et al.* [13] examined the optimal decisions of delivery lead time and prices in a centralized and a decentralized dual-channel supply chain using the two-stage optimization technique and Stackelberg game, and analyzed the impacts of delivery lead time and customer acceptance of a direct channel on the manufacturer's and retailer's pricing behaviors. Xu *et al.* [38] extended the work of Chiang *et al.* [4] by investigating how price and delivery lead time decisions affect channel configuration strategy under either the manufacturer-owned or the decentralized mode.

Previous studies have extensively researched pricing strategies with consideration of retail service or manufacturer service in dual-channel supply chain. But in this paper, we analyze retail service and direct service simultaneously in a centralized and decentralized dual-channel supply chain. Between the manufacturer and the retailer, there exists service competition, *i.e.*, higher service level in one channel will attract more customers, leading to less demand in the other channel.

2.2. Quality effort

The manufacturer can invest in new technology or strengthen the production control process to enhance the product quality and attract more customers [21]. Xu [37] and Shi *et al.* [29] investigated price and quality decisions under the assumption that the manufacturer can sell a single product either through a direct channel or through a retailer. Ma *et al.* [22] mainly discussed the quality effort and sales effort decisions under three supply chain modes: the centralized mode, the decentralized modes leaded by the manufacturer and the retailer respectively. Ma *et al.* [23] investigated the issue of channel coordination for a two-stage supply chain with one retailer and one manufacturer. The demand was influenced by the retailer's sales effort and manufacturer's quality improvement effort. Pal *et al.* [26] dealt with the two-echelon supply chain model of one manufacturer and one retailer for a single commodity where market demand was assumed to be dependent on selling price,

Table 1. Notation.

Parameters:	
c	Unit cost of the manufacturer
w	Whole sale price
p_m	The direct sale price
p_r	The retail price
e_m	The level of the manufacturer's direct services
e_r	The level of the retail services
θ	The level of new product's quality
ξ_1	The service cost coefficient of direct channel
ξ_2	The service cost coefficient of retail channel
η	The unit quality investment
a	The basic market demand of new products
δ	The degree of customer loyalty to the direct channel
D_r	The demands of new products in the retail channel
D_m	The demands of new products in the direct channel

quality of the products, and promotional effort of the retailer. They investigated the behavior of the supply chain under centralized, manufacturer Stackelberg, conditional manufacturer Stackelberg, retailer Stackelberg, conditional retailer Stackelberg, and vertical Nash model structure. But the dual channel that consists of direct and retail channels was not considered. Chen *et al.* [3] investigated price and quality decisions in dual-channel supply chains, in which a single product was delivered through a retail channel, a direct channel, or a dual channel with both retail and direct channels.

Our paper is also related to the omni-channel management which has received a lot of attention in recent years. Ofek *et al.* [25] studied the impact of product returns on a multichannel retailer and examined how pricing strategies and physical store assistance levels change as a result of the additional online outlet. Zhang *et al.* [40] investigated a retailer's channel structure choice and pricing decisions in a supply chain under three possible alternatives: a pure offline channel, a pure online channel, and dual channels. Choi *et al.* [5] explored online-offline fashion franchising supply chains without channel conflicts with the focal points on the choice of franchising contract and the ordering time. In this paper, we assume that the price in the direct channel is equal to that in the retail channel, *i.e.*, consistent pricing strategy. According to Ernst and Young [9], about two thirds of dual-channel companies utilize consistent pricing, whereas the remaining companies use inconsistent pricing.

The key difference between our work and the aforementioned studies is that our work investigates the quality, services, and pricing decisions in the dual-channel supply chain context with the price, quality effort, and services dependent demand. To the best of our knowledge, very few research results on price, quality, and services decisions in a dual-channel supply chain under different channel structures have been established, which highlights the research objectives and contributions of this paper. Therefore, this paper can provide useful theoretical and managerial insights on the operation of dual-channel supply chain with consideration of retail service, direct service and quality effort.

3. Model development

This paper considers a dual-channel supply chain consisting of a manufacturer with a direct channel and a retailer with a physical store. In addition to the traditional retail channel, the manufacturer can sell a new product through his direct channel. Customers can buy products through either the direct channel or the retail channel depending on their preference. Table 1 lists the notation used in this paper.

To establish the model, some assumptions are provided as follows:

Assumption 3.1. *The demands faced by the manufacturer and the retailer are linear functions of the selling prices, quality effort level, the level of retail services, and the level of manufacturer services. Both demands, in the retail channel and the direct channel, are assumed downward sloping in selling prices and upward sloping in quality effort level. Moreover, the demand is increasing in its own channel service level and decreasing in the other channel service level. This assumption is similar to Wang and Zhao [35].*

Thus, the demand functions in the direct channel and the retail channel are as follows:

$$D_m = \delta a - b_1 p_m + b_2 p_r + \gamma_1 \theta + \beta_1 e_m - \beta_2 e_r, \tag{1}$$

$$D_r = (1-\delta)a - b_1 p_r + b_2 p_m + \gamma_2 \theta + \beta_1 e_r - \beta_2 e_m, \tag{2}$$

where D_m and D_r are the demands of new products in the retail channel and direct channel, respectively. a is the basic market demand of new products and is a constant. δ is the degree of customer loyalty to the direct channel, and $1-\delta$ is the degree of customer loyalty to the retail channel; $0 \leq \delta \leq 1$. We assume $\gamma_1 < \gamma_2$ because customers can examine the products thoroughly when they see the actual products. In addition, p_m and p_r represent the selling prices in the direct channel and traditional retail channel, respectively. b_1 is the marginal channel demand per respective channel price, and b_2 is cross-price sensitivity, which means the demand shifts between the two channels with respect to the selling prices, whereas $b_1 > b_2$ indicates that one channel's own price effect is greater than the cross-price effect [17, 18]. In addition, increasing service level will trigger two phenomena: (a) a group of customers will decide to switch from the other channel to buy the product; (b) a group of customers who otherwise would not purchase in any channel, then, we assume $\beta_1 > \beta_2$ is reasonable [35]. Linear demand functions have been adopted in Chiang *et al.* [4], Huang and Swaminathan [14], Hua *et al.* [13], Dan *et al.* [6], and many others.

Assumption 3.2. *Following Li et al. [18] and Taleizadeh et al. [31], for relieving channel conflicts, we assume that the prices in two channels are equal, i.e., $p_m = p_r = p$. In other words, the manufacturer and the retailer set the same price for both direct online channel and the indirect retail channel.*

This assumption relates to the omni-channel retailing model commonly adopted by many companies nowadays. To avoid the trivial case, we assume $p \geq w \geq c$, here p is the selling price of the product, w is the per-unit wholesale price of the product decided by the manufacturer, and c is the per-unit manufacturing cost of the product. Consequently, the demand functions can be written as follows:

$$D_m = \delta a - bp + \gamma_1 \theta + \beta_1 e_m - \beta_2 e_r, \tag{3}$$

$$D_r = (1-\delta)a - bp + \gamma_2 \theta + \beta_1 e_r - \beta_2 e_m, \tag{4}$$

where $b = b_1 - b_2$.

Assumption 3.3. *In this model, we also assume the manufacturer can increase the final demand by exerting quality effort θ on the product and direct service level e_m on the direct channel. And the costs are assumed as an increasing and convex function of sales efforts, defined as $\frac{1}{2}\eta\theta^2$, $\frac{1}{2}\xi_1 e_m^2$, respectively [22, 23, 35]. For the retailer, we also assume the retailer can positively influence the market demand by exerting retail service level e_r; and the cost is $\frac{1}{2}\xi_2 e_r^2$, i.e., ξ_2 is the unit cost.*

Such a quadratic cost function is commonly used in previous literature. To be specific, manufacturer service on the direct channel includes e-channel advertising, money back guarantees, and free shipping. In addition, the retail service refers to all forms of demand-enhancing services provided by the retailer, which contain advertising the products' features, providing attractive shelf space, and point-of-sale demonstrations.

Assumption 3.4. *The basic market demand is sufficiently large and greater than the other parameters of the model.*

Before discussing the model, two conditions must be satisfied. First, the demands in both the direct channel and the retail channel must be non-negative. Second, the manufacturer and the retailer must gain non-negative profits. These two conditions can be rewritten as follows:

$$c \leq w \leq p \leq \min\left\{\frac{\delta a + \gamma_1\theta + \beta_1 e_m - \beta_2 e_r}{b}, \frac{(1-\delta)a + \gamma_2\theta + \beta_1 e_r - \beta_2 e_m}{b}\right\}. \tag{5}$$

Then the manufacturer's profit function and the retailer's profit function are the following:

$$\begin{aligned}\pi_m &= (w-c)[(1-\delta)a - bp + \gamma_2\theta + \beta_1 e_r - \beta_2 e_m] \\ &\quad + (p-c)(\delta a - bp + \gamma_1\theta + \beta_1 e_m - \beta_2 e_r) - \frac{1}{2}\eta\theta^2 - \frac{1}{2}\xi_1 e_m^2, \end{aligned} \tag{6}$$

$$\pi_r = (p-w)[(1-\delta)a - bp + \gamma_2\theta + \beta_1 e_r - \beta_2 e_m] - \frac{1}{2}\xi_2 e_r^2. \tag{7}$$

The following section considers a centralized system in which all the decisions are centralized to maximize the performance of the entire supply chain, that is, the manufacturer is vertically integrated with the retailer in the retail channel. The manufacturer controls all three decisions: quality effort level, the direct service level and the selling price. Then, retailer only determines the retail service level. The centralized system solution serves as a benchmark for the decentralized setting. Next, we consider a decentralized supply chain under the Stackelberg game led by the manufacturer. The decision process is assumed to follow the following sequence: the manufacturer, as the Stackelberg leader, determines the wholesale price, quality effort level, and the direct service level; then the retailer needs to set his own optimal selling price and retail service level based on the manufacturer's decisions. Due to their complexity, we analyze the problems by two-stage optimization. The first stage derives the optimal retail service level for any given selling price. In the second stage, the optimal price is determined based on the results obtained in the first stage. Lastly, for the decentralized situation, it is assumed that information is common knowledge to both parties.

4. Model solutions and discussions

This section derives the optimal decisions for the manufacturer and the retailer in the centralized and the decentralized dual channel supply chains, respectively. Then, we compare the optimal decisions between the two supply chain structures to find which one is more beneficial to the supply chain. To obtain some managerial insights, we perform analyses and discussions about the optimal decisions, such as sensitivity analyses of parameters and decision variables.

4.1. Centralized dual-channel supply chain model

In the centralized model, the total demand of the dual-channel supply chain is $D = D_m + D_r$. Thus, the total profit is

$$\begin{aligned}\pi_c &= (p-c)D - \frac{1}{2}\eta\theta^2 - \frac{1}{2}\xi_1 e_m^2 - \frac{1}{2}\xi_2 e_r^2 \\ &= (p-c)[a - 2bp + (\gamma_1+\gamma_2)\theta + (\beta_1-\beta_2)(e_m+e_r)] - \frac{1}{2}\eta\theta^2 - \frac{1}{2}\xi_1 e_m^2 - \frac{1}{2}\xi_2 e_r^2. \end{aligned} \tag{8}$$

In order to maximize π_c, we examine some properties regarding π_c which are expressed in Proposition 4.1.

Proposition 4.1. *The total profit of the centralized dual-channel supply chain π_c is strictly jointly concave in θ, e_m, and e_r, concave in p; but not jointly concave in all four decision variables.*

Proposition 4.1 indicates that we cannot find the optimal solutions of p, θ, e_m, and e_r by using only the first-order conditions. However, Proposition 4.1 shows that π_c has a unique optimal solution for any given p, so we can deal with it using the two-stage optimization technique, *i.e.*, we first find the optimal value of π_c for a given p, and then find the optimal p to maximize π_c.

Proposition 4.2. *For any given selling price, the optimal quality effort level, the direct service level, and retail service level are given by*

$$\theta_c(p) = \frac{(p-c)(\gamma_1+\gamma_2)}{\eta}, \tag{9}$$

$$e_{mc}(p) = \frac{(p-c)(\beta_1-\beta_2)}{\xi_1}, \tag{10}$$

$$e_{rc}(p) = \frac{(p-c)(\beta_1-\beta_2)}{\xi_2}, \tag{11}$$

and the total profit $\pi_c(p)$ as a function of p is given by

$$\pi_c(p) = (p-c)(a-2bp) + [\frac{(\gamma_1+\gamma_2)^2}{2\eta} + \frac{(\beta_1-\beta_2)^2}{2\xi_1} + \frac{(\beta_1-\beta_2)^2}{2\xi_2}](p-c)^2. \tag{12}$$

From (9)–(11), we can intuitively know that manufacturer's quality effort level and direct service level, retail service level are only increasing with profit margin, *i.e.*, $p-c$. To find the optimal p to maximize $\pi_c(p)$, we differentiate $\pi_c(p)$ with respect to p, which yields the first-order condition: $\frac{\partial \pi_c(p)}{\partial p} = a + 2bc + (-4b + \frac{\gamma^2}{\eta} + \frac{\beta^2}{\xi_1} + \frac{\beta^2}{\xi_2})p - (\frac{\gamma^2}{\eta} + \frac{\beta^2}{\xi_1} + \frac{\beta^2}{\xi_2})c = 0$, *i.e.*, $\gamma = \gamma_1 + \gamma_2$, $\beta = \beta_1 - \beta_2$; then we can get optimal decisions and corresponding total profit which are expressed in following Proposition 4.3.

Proposition 4.3. *For the centralized dual-channel supply chain, optimal decisions are: $p_c^* = \frac{a-2bc}{A} + c$, $\theta_c^* = \frac{\gamma(a-2bc)}{\eta A}$, $e_m^* = \frac{\beta(a-2bc)}{\xi_1 A}$, and $e_r^* = \frac{\beta(a-2bc)}{\xi_2 A}$, respectively; then the corresponding optimal profit $\pi_c^* = \frac{(a-2bc)^2}{2A}$, where $A = 4b - \frac{\beta^2(\xi_1+\xi_2)}{\xi_1\xi_2} > 0$.*

As the above proposition implies, the degree of customer loyalty to the direct channel has no effect on all decisions and corresponding total profits. The reason is intuitive that the manufacturer and the retailer operate as a centralized system. They make decisions no matter which channel customers choose to buy. Proposition 4.3 also shows that the manufacturer's quality effort level is increasing with γ, but decreasing with η. This result implies that when the impact of manufacturer's quality effort on the total demand is large and the quality cost coefficient is relatively small, the manufacturer will exert more quality efforts. In addition, the relative size of service levels that the manufacturer and retailer exert, respectively, is contingent on the unit cost of service of each channel. More specifically, the party whose unit cost of sales effort is lower should put more efforts into promoting sales, as a result, leading to higher profits.

The centralized scenario is the benchmark for decision making in dual-channel supply chain. Prior issues suggest that centralized channel always outperforms decentralized channel as there is no "double marginalization" having only one decision maker [24]. Next, we consider that the manufacturer and the retailer are independent in the decentralized model and make their own decisions to maximize their profits. We aim to study whether double marginalization exists in the decentralized dual-channel supply chain analyzed in the next subsection. Specifically, the manufacturer takes the retailer's response functions into consideration to decide wholesale price, quality effort level, and direct service level; the retailer decides the selling price and retail service level based on manufacturer's decisions. Then we present the method to decide the Stackelberg equilibrium strategies of the two parties.

4.2. Decentralized dual-channel supply chain model

4.2.1. Retailer's best response

The retailer's best response to quality effort level θ, wholesale price w, and direct service level e_m set by the manufacturer is given in the following proposition.

Proposition 4.4. *For given p, w, θ, and e_m, the retailer's best service strategy e_r is given by $e_r^d(p,w,\theta,e_m) = \frac{\beta_1(p-w)}{\xi_2}$; and the retailer's optimal profit π_r^d is given by $\pi_r^d(p,w,\theta,e_m) = (p-w)[(1-\delta)a - bp + \gamma_2\theta + \dfrac{\beta_1^2(p-w)}{\xi_2} - \beta_2 e_m] - \frac{\beta_1^2(p-w)^2}{2\xi_2}$.*

To examine the impact of p, w, θ, and e_m on the retailer's best service strategy and corresponding profit, we take the first-order partial derivatives of $e_r^d(p,w,\theta,e_m)$ and $\pi_r^d(p,w,\theta,e_m)$ with respect to p, w, θ, and e_m, respectively, and obtain the following proposition.

Proposition 4.5. *(i) $\frac{\partial e_r^d}{\partial w} = -\frac{\beta_1}{\xi_2}$;*

(ii) $e_r^d \le e_{rc}(p)$ if $\frac{p-c}{p-w} \ge \frac{\beta_1}{\beta_1-\beta_2}$; otherwise, $e_r^d > e_{rc}(p)$;

(iii) $\frac{\partial \pi_r^d}{\partial \delta} = -a(p-w) < 0$; $\frac{\partial \pi_r^d}{\partial \theta} = \gamma_2(p-w) > 0$; $\frac{\partial \pi_r^d}{\partial e_m} = -\beta_2(p-w) < 0$; $\frac{\partial \pi_r^d}{\partial w} = -[(1-\delta)a - bp + \gamma_2\theta + \frac{\beta_1^2(p-w)}{\xi_2} - \beta_2 e_m] < 0$.

Proposition 4.5 (i) indicates that the retailer's best service level e_r^d decreases with increasing w. It means that the retailer will put more energy into promoting product sales only if the profit margin of selling one unit is larger. Note that $p-c$ and $p-w$ represent the profit margins of selling one unit from centralized and decentralized dual-channel supply chain for the retailer, respectively. Let $\rho = \frac{p-c}{p-w}$ mean the ratio of those two profit margins. From Proposition 4.5 (ii), we can find that the ρ determines the retailer's service strategy. More specifically, it exists a threshold, *i.e.*, $\frac{\beta_1}{\beta_1-\beta_2}$; if ρ is larger than the threshold, the optimal retail service level in centralized dual-channel supply chain is larger than that in decentralized dual-channel supply chain. Correspondingly, if ρ is smaller, then the retailer is willing to put more efforts as many as he can in the decentralized model. And if ρ is equal to the threshold, the retailer will exert same service level in different channel structures. In other words, ρ is very important for the retailer to make optimal service decisions. Proposition 4.5 (iii) shows that the retailer's profit π_r^d increases with increasing θ, and decreases with increasing δ, e_m, and w, which is reasonable because, intuitively, if the base level of the demand in retail channel is small, the retailer's profit would decrease. Similarly, the retailer's marginal profit will decrease with increasing w. But, when the manufacturer invests more to improve products' quality, customers will have higher willingness-to-pay for them; then the retailer's profit would increase by raising the selling price.

4.2.2. Manufacturer's pricing strategy

Substituting e_r into Equation (6), we can derive an expression for π_m^d in terms of p, w, θ, and e_m:

$$\begin{aligned}\pi_m^d(p,w,\theta,e_m) = (w-c)[(1-\delta)a - bp + \gamma_2\theta + \frac{\beta_1^2(p-w)}{\xi_2} - \beta_2 e_m] \\ + (p-c)(\delta a - bp + \gamma_1\theta + \beta_1 e_m - \frac{\beta_1\beta_2(p-w)}{\xi_2}) - \frac{1}{2}\eta\theta^2 - \frac{1}{2}\xi_1 e_m^2. \end{aligned} \tag{13}$$

For any given p, if $\eta > \frac{\xi_1\xi_2\gamma_2^2}{2\xi_1\beta_1^2 - \xi_2\beta_2^2}$, then π_m^d is jointly concave on w, θ, and e_m. From the first-order conditions for π_m^d, we have the optimal solution as follows proposition.

Proposition 4.6. *For any given retail price, the manufacturer's optimal wholesale price, quality effort level, and direct service level are given as follows:*

$$w^d(p) = \frac{(1-\delta)a + Bp + Dc}{E}, \tag{14}$$

$$\theta^d(p) = \frac{(w-c)\gamma_2 + (p-c)\gamma_1}{\eta} = \frac{\gamma_2(1-\delta)a + (\gamma_2 B + \gamma_1 E)p + (\gamma_2(D-E) - \gamma_1 E)c}{\eta E}, \tag{15}$$

$$e_m^d(p) = \frac{(w-c)(-\beta_2) + (p-c)\beta_1}{\xi_1} = \frac{-\beta_2(1-\delta)a + (\beta_1 E - \beta_2 B)p + (\beta_2(E-D) - \beta_1 E)c}{\xi_1 E}, \tag{16}$$

where $B = -b + \frac{\gamma_1\gamma_2}{\eta} + \frac{\beta_1^2+\beta_1\beta_2}{\xi_2} - \frac{\beta_1\beta_2}{\xi_1}$, $D = -\frac{\gamma_2(\gamma_1+\gamma_2)}{\eta} + \frac{\beta_1^2-\beta_1\beta_2}{\xi_2} + \frac{\beta_2(\beta_1-\beta_2)}{\xi_1}$, $E = \frac{2\beta_1^2}{\xi_2} - \frac{\beta_2^2}{\xi_1} - \frac{\gamma_2^2}{\eta} > 0$.

From (14)–(16), to examine the impact of δ and retail price p on the manufacturer's best strategies, we take the first-order derivatives of $w^d(p)$, $\theta^d(p)$, $e_m^d(p)$ with respect to δ and p, respectively, and compared to that in the centralized setting; then we obtain the following proposition.

Proposition 4.7. *(i)* $\frac{\partial w^d(p)}{\partial \delta} = \frac{-a}{E} < 0$, $\frac{\partial \theta^d(p)}{\partial \delta} = \frac{-a\gamma_2}{\eta E} < 0$, $\frac{\partial e_m^d(p)}{\partial \delta} = \frac{a\beta_2}{\xi_1 E} > 0$;

(ii) if $0 < b < \frac{\gamma_1\gamma_2}{\eta} + \frac{\beta_1^2+\beta_1\beta_2}{\xi_2} - \frac{\beta_1\beta_2}{\xi_1}$, $\frac{\partial w^d(p)}{\partial p} = \frac{B}{E} > 0$, $\frac{\partial \theta^d(p)}{\partial p} = \frac{\gamma_1+\frac{\gamma_2 B}{E}}{\eta} \geq \frac{\partial \theta^c(p)}{\partial p}$, $\frac{\partial e_m^d(p)}{\partial p} = \frac{\beta_1-\frac{\beta_2 B}{E}}{\xi_1} > \frac{\partial e_{mc}(p)}{\partial p}$;

(iii) if $\frac{\gamma_1\gamma_2}{\eta} + \frac{\beta_1^2+\beta_1\beta_2}{\xi_2} - \frac{\beta_1\beta_2}{\xi_1} < b \leq \frac{\gamma_1\gamma_2-\gamma_2^2}{\eta} + \frac{3\beta_1^2+\beta_1\beta_2}{\xi_2} - \frac{\beta_1\beta_2+\beta_2^2}{\xi_1}$, $\frac{\partial w^d(p)}{\partial p} = \frac{B}{E} < 0$, $\frac{\partial \theta^d(p)}{\partial p} = \frac{\gamma_1+\frac{\gamma_2 B}{E}}{\eta} \geq \frac{\partial \theta^c(p)}{\partial p}$, $\frac{\partial e_m^d(p)}{\partial p} = \frac{\beta_1-\frac{\beta_2 B}{E}}{\xi_1} > \frac{\partial e_{mc}(p)}{\partial p}$;

(iv) if $b > \frac{\gamma_1\gamma_2-\gamma_2^2}{\eta} + \frac{3\beta_1^2+\beta_1\beta_2}{\xi_2} - \frac{\beta_1\beta_2+\beta_2^2}{\xi_1}$, $\frac{\partial w^d(p)}{\partial p} = \frac{B}{E} < 0$, $\frac{\partial \theta^d(p)}{\partial p} = \frac{\gamma_1+\frac{\gamma_2 B}{E}}{\eta} < \frac{\partial \theta^c(p)}{\partial p}$, $\frac{\partial e_m^d(p)}{\partial p} = \frac{\beta_1-\frac{\beta_2 B}{E}}{\xi_1} > \frac{\partial e_{mc}(p)}{\partial p}$;

Proposition 4.7 (i) shows that the quality effort level and the wholesale price decrease, but direct service level increases as δ increases. When δ is large, the basic demand in the direct channel is also large. For the same quality degree, the effect on customers in the retail channel is greater than that in the direct channel because customers can examine the products thoroughly when they see the actual products. Therefore, the relatively lower product quality has less effect on the direct demand. Motivated by this, the manufacturer invests less money in product innovation. Of course, the per-unit cost of the new products is relatively low; therefore, the wholesale price is also low. But the manufacturer needs to input more sales effort or services to guarantee the satisfaction of customers. This result presents the drawback of operating a single channel. From the point view of customers, on one hand, they can enjoy more convenience of online direct channel; on the other hand, they can also examine the new product thoroughly in the offline stores to guarantee product fit.

Next, Proposition (ii)–(iv) indicate that when b is more than a threshold, wholesale price w decreases as p increases; however, when b is less than a threshold, the wholesale price increases as p increases. This phenomenon is straightforward because when b is more than a threshold, the change of selling price has significantly negative impact on the demands. To ensure the demand of retail channel is non-negative, the manufacturer needs to decline the wholesale price. Compared to quality effort levels in centralized and decentralized models, we find when η is greater than a threshold, the rate of change of quality effort level with respect to selling price is larger in centralized model than that in decentralized model. When η is less than a threshold, the rate of change of quality effort level with respect to selling price is larger in decentralized model. In addition, the rate of change of direct service level with respect to selling price is larger in decentralized model than that in centralized model regardless of the size of b. The reason is that the channel price in the centralized dual-channel supply chain is the manufacturer's decision variable, but under decentralized scenario is the retailer's decision variable. Therefore, the manufacturer should increase direct service level to get more profits in the decentralized dual-channel supply chain.

Furthermore, from Propositions 4.4 and 4.6, we can derive the optimal retail service level and profit which are presented in following proposition.

Proposition 4.8. *For any given selling price, the retailer's optimal retail service level and optimal profit are given by:*

$$e_r^d(p) = \frac{\beta_1[-(1-\delta)a + (E-B)p - Dc]}{\xi_2 E}, \tag{17}$$

$$\begin{aligned} \pi_r^d(p) = &-\frac{(B-E)[2(BG+EF)\xi_2 + (E-B)\beta_1^2]p^2}{2\xi_2 E^2} \\ &-\frac{((Dc-a\delta+a)(2(BG+EF)\xi_2 + (E-B)\beta_1^2) + (B-E)(2(DG-EH)c\xi_2 - Dc\beta_1^2 - 2(E+G)a\xi_2\delta + a\beta_1^2(\delta-1) + 2(E+G)a\xi_2))p}{2\xi_2 E^2} \\ &-\frac{(Dc-a\delta+a)(2(DG-EH)c\xi_2 - Dc\beta_1^2 - 2(E+G)a\xi_2\delta + a\beta_1^2\delta + 2(E+G)a\xi_2 - a\beta_1^2)}{2\xi_2 E^2}, \end{aligned} \tag{18}$$

where $F = -b + \frac{\gamma_1\gamma_2}{\eta} - \frac{\beta_1\beta_2}{\xi_1}$, $G = \frac{\gamma_2^2}{\eta} + \frac{\beta_2^2}{\xi_1}$, *and* $H = \frac{\gamma_2(\gamma_1+\gamma_2)}{\eta} + \frac{\beta_2(\beta_2-\beta_1)}{\xi_1}$.

From (17), $\frac{\partial e_r^d(p)}{\partial \delta} = \frac{a\beta_1}{\xi_2 E} > 0$, *i.e.*, for any given retail price, the optimal retail service level will increase with increasing δ, which is not intuitive; because under normal circumstances, if the base level of the demand in one channel is large, then the service level in that channel should be set high. This result implies when more and more customers prefer to choose direct channel with the rapid development of e-commence, the retailer must recognize that retail service is a critical factor in guaranteeing the retail demand and expanding the market. This result motivates retailers to provide and improve retail service levels to attract customers under competition, including presale service (counseling service, product advertising, etc.), in-sale service (on-time product delivery, etc.), and after sale service (subsequent tracking service, etc.) [35].

To find the optimal p to maximize $\pi_r^d(p)$, we differentiate $\pi_r^d(p)$ with respect to p, which yields the first-order condition:

$$\begin{aligned}\frac{\partial \pi_r^d(p)}{\partial p} &= -\frac{(B-E)[2(BG+EF)\xi_2 + (E-B)\beta_1^2]p}{\xi_2 E^2} \\ &\quad - \frac{((Dc - a\delta + a)(2(BG+EF)\xi_2 + (E-B)\beta_1^2) + (B-E)(2(DG-EH)c\xi_2 - Dc\beta_1^2 - 2(E+G)a\xi_2\delta + a\beta_1^2(\delta-1) + 2(E+G)a\xi_2))}{2\xi_2 E^2} \\ &= 0, \end{aligned} \tag{19}$$

i.e.,

$$p^* = \frac{-((\delta-1)a + Hc)\xi_2 E^2 + (((\delta-1)(B+F-G)a + c(BH - D(F-G)))\xi_2 - \beta_1^2((1-\delta)a + Dc))E - 2(G\xi_2 - \frac{\beta_1^2}{2})((1-\delta)a + Dc)B}{(B-E)(2(BG+EF)\xi_2 + (E-B)\beta_1^2)}. \tag{20}$$

Substituting the optimal p^* into (14)–(17), we obtain the equilibrium decisions for the manufacturer and the retailer.

5. Numerical studies

In this section, we first compare the total profits between the centralized and decentralized dual-channel supply chain. Then, we illustrate the effects of the degree of customer loyalty to the direct channel on selling price, quality effort level, direct and retail services levels in both the centralized dual-channel supply chain and the decentralized dual-channel supply chain through numerical experiments. The related parameters are assumed to be $a = 1200$, $c = 30$, $b = 7$, $\gamma_1 = 5$, $\gamma_2 = 6$, $\beta_1 = 5$, $\beta_2 = 3$, $\eta = 8$, $\xi_1 = 4$, $\xi_2 = 6$.

5.1. The impact of δ on optimal total profits in centralized and decentralized models

Figure 1 shows that the retailer's profit decreases with increasing the degree of customer loyalty to the direct channel in decentralized dual-channel supply chain; and the manufacturer's profit is concave in the degree of customer loyalty to the direct channel. This means that, on one hand, the less base level of the retail channel is, the lower the retail price should be, leading to less profit for the retailer. On the other hand, the manufacturer benefits less when the degree of customer loyalty to the direct channel is lower or sufficiently higher. In other words, the manufacturer is more profitable on the condition that relatively higher segments of customers choose to buy in direct channel, while relatively lower fraction of them choose the retail channel. In addition, we also find that a decentralized dual-channel supply chain yields higher profits than a centralized dual-channel supply chain. This finding is in sharp contrast to prior research, which suggests that centralized channel always outperform decentralized channel as there is no "double marginalization" having a single decision maker.

5.2. The impact of δ on optimal selling price in centralized and decentralized models

We know that the higher the base level of demand in a single sale channel is, the higher the optimal selling price is. In our model, for relieving channel conflicts, we assume that the prices in two channels are equal. The above results indeed show that this observation also holds for the dual-channel supply chain, *i.e.*, generally

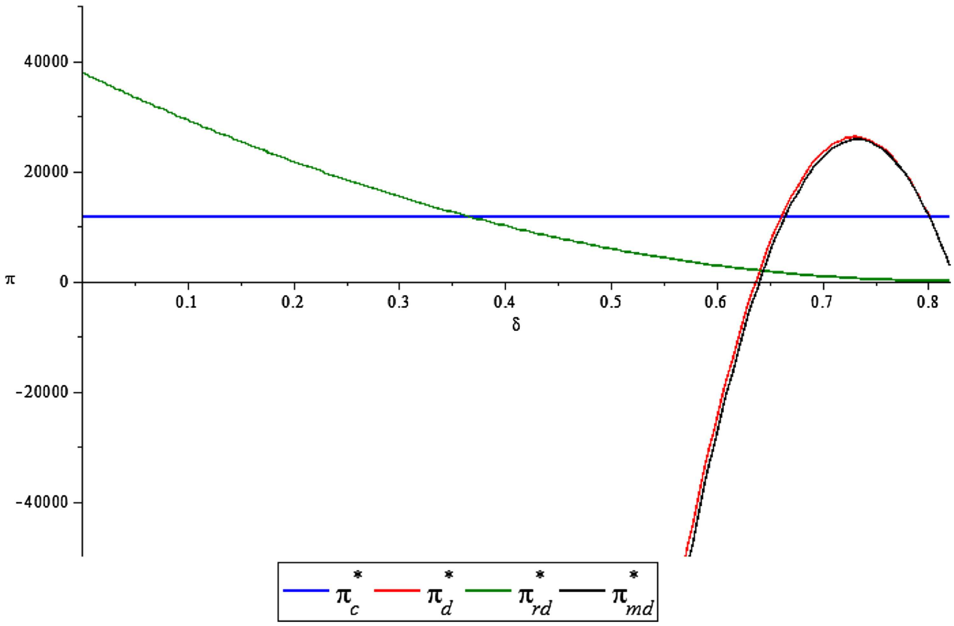

Figure 1. Optimal total profits in centralized and decentralized dual-channel supply chain.

speaking, the lower the base level of demand in retail channel is, the lower the selling price in dual-channel is. Moreover, when decentralized dual-channel supply chain yields more profits, its selling price is either higher or lower than that in the centralized dual-channel supply chain. This implies that higher profits in decentralized dual-channel supply chain result from quality effort, direct service, or retail service when the selling price is higher.

5.3. The impact of δ on optimal quality effort level in centralized and decentralized models

Figure 2b indicates that when the degree of customer loyalty to the direct channel is relatively low, the quality-improvement effort in the decentralized case is higher than that in the centralized case. However, when the degree of customer loyalty to the direct channel is relatively high (*e.g.*, higher than a threshold), the quality effort level will be set lower in decentralized dual-channel supply chain. This indicates that when more customers buy products online, they instead obtain lower quality ones finally. This finding is consistent with reality: because customers can only examine the products thoroughly in the retail channel.

5.4. The impact of δ on optimal direct service level in centralized and decentralized models

Figure 2c intuitively shows that the direct service level decreases with the degree of customer loyalty to the direct channel. And when the degree of customer loyalty to the direct channel is relatively low, the direct service level should be set higher in decentralized dual-channel supply chain. However, when the degree of customer loyalty to the direct channel is relatively high (*e.g.*, higher than a threshold), the direct service level will be set lower than that in the centralized case. In other words, if the base level of demand in the direct channel is relatively high, then the manufacturer will input less efforts.

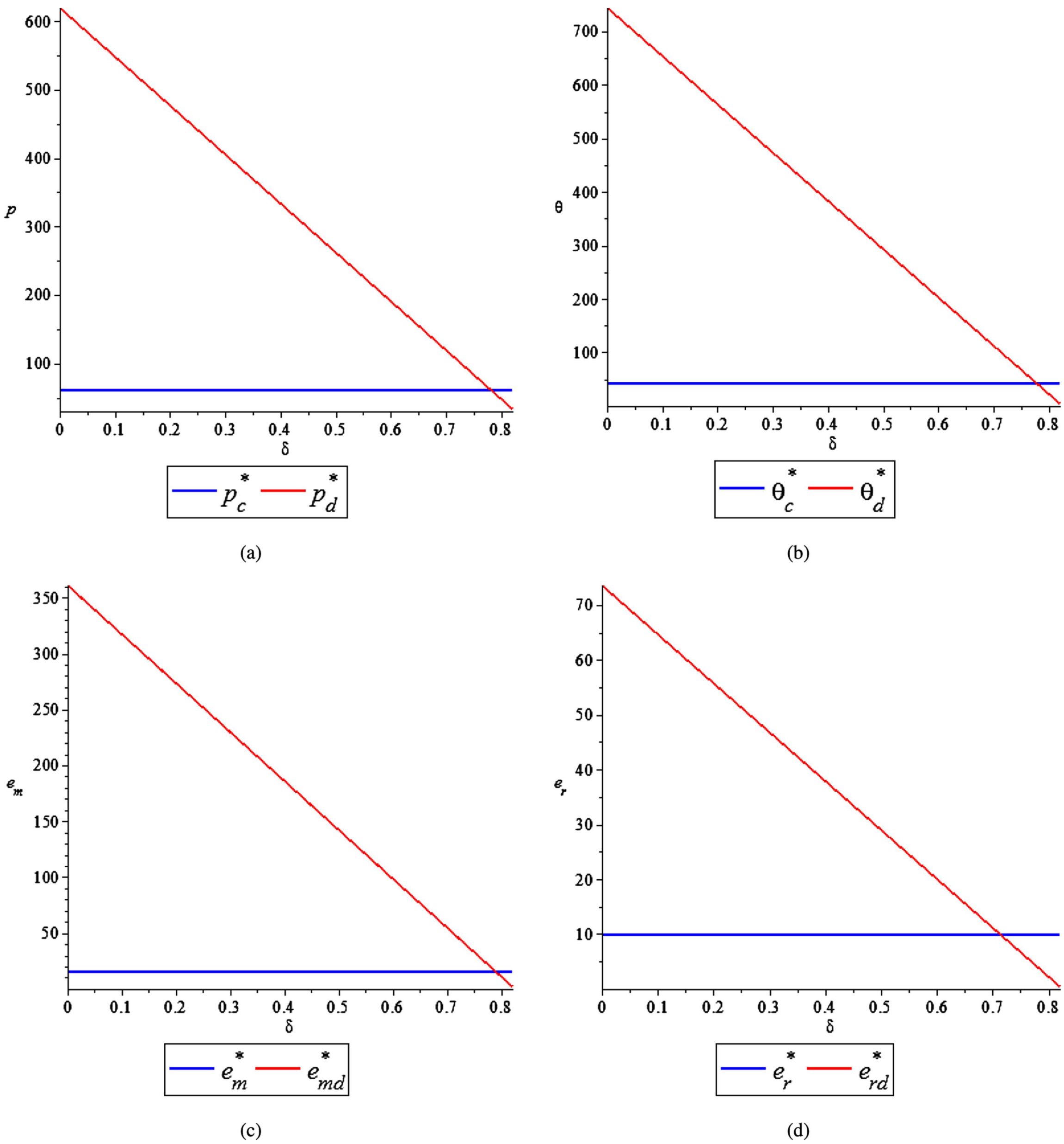

FIGURE 2. The impact of δ on p, θ, e_m, and e_r.

5.5. The impact of δ on optimal retail service level in centralized and decentralized models

Similar to the direct service, when the degree of customer loyalty to the direct channel is relatively low, the retail service level should be set higher in decentralized dual-channel supply chain. However, when the degree of customer loyalty to the direct channel is relatively high (*e.g.*, higher than a threshold), the retail service will be set lower than that in the centralized case. In other words, the manufacturer and the retailer will put more efforts if the base level of demand or demand rate in the retail channel is relatively high. On the contrary, less sales efforts are made to promote the demands if the base level of demand or demand rate in the direct channel is relatively high.

From the above numerical studies, we observe that when the degree of customer loyalty to the direct channel is located in the interval $[0.6610, 0.7144]$, the optimal total profits, quality effort level, direct sales effort level, and retail service level are higher in the decentralized dual-channel supply chain. This result provides new insights into dual-channel supply chain management. More specifically, the manufacturer with a online direct channel should cooperate but not exert potential competition pressure on the retailer. For customers, online shopping is very popular and has many benefits such as energy and time saving. And the traditional retail channel has the necessity of existence; customers can examine the product in the physical store. Moreover, the direct channel should account for relatively larger market share; and selling through single channel benefits less for the manufacturer and the retailer.

6. Conclusion

This paper introduces retail service, direct service, and manufacturer's quality effort into the dual-channel supply chain and discusses the pricing, quality, and services strategies for the members in both centralized and decentralized cases using the two-stage optimization technique in Stackelberg game. Furthermore, we compare the manufacturer's and the retailer's decisions between the centralized and decentralized dual-channel supply chain under a consistent pricing strategy. We provide a decision making aid for the manufacturer and the retailer; our results indicate that services, quality, and price decisions are very important for them. The main findings of this paper are as follows:

(1) In the centralized system, the degree of customer loyalty to direct channel has no effect on all optimal decisions and corresponding total profits. In addition, the levels of services that manufacturer and retailer exert, respectively, are contingent on the unit cost of service of each channel. More specifically, the party whose unit cost of service is lower should put more efforts into promoting sales.
(2) Compared to the centralized system, for any given selling price, the ratio of profit margins of selling one unit in the direct and retail channels determines the retailer's service level in the decentralized model. If this ratio is larger than the threshold, the optimal retail service level in the centralized system is larger than that in the decentralized system. Moreover, for the manufacturer, he will promote the level of direct channel service, but put less efforts on quality improvement in the decentralized model.
(3) Our numerical studies show that the manufacturer is more profitable on the condition that relatively higher segments of customers choose to buy in direct channel, while relatively lower fractions of them choose the retail channel. In addition, we present the contrasting view that disparate interests within a dual-channel supply chain can actually realize improving outcomes. In fact, decentralized supply chain sometimes performs strictly better than the centralized system [30].

Our work also has some limitations. First, decentralization has generally been associated with coordination problems. In this paper, due to computational complexity, we don't give a discussion of coordinated setting between the manufacturer and the retailer. One possible direction would be to design an incentive contract to encourage both parties to increase their services levels. Another direction is considering stochastic demand, which may provide additional insights to the dual-channel problem. Finally, we regard all information as symmetric one in this study, therefore, considering the asymmetric information can be regarded as a plausible research direction.

Appendix A.

A.1. Proof of proposition 4.1

Taking the second-order partial derivatives of π_c with respect to p, θ, e_m, and e_r, we have the Hessian matrix

$$H^{\pi_r}=\begin{bmatrix}\frac{\partial^2\pi_r}{\partial p^2} & \frac{\partial^2\pi_r}{\partial p\partial\theta} & \frac{\partial^2\pi_r}{\partial p\partial e_m} & \frac{\partial^2\pi_r}{\partial p\partial e_r}\\ \frac{\partial^2\pi_r}{\partial\theta\partial p} & \frac{\partial^2\pi_r}{\partial\theta^2} & \frac{\partial^2\pi_r}{\partial\theta\partial e_m} & \frac{\partial^2\pi_r}{\partial\theta\partial e_r}\\ \frac{\partial^2\pi_r}{\partial e_m\partial p} & \frac{\partial^2\pi_r}{\partial e_m\partial\theta} & \frac{\partial^2\pi_r}{\partial e_m^2} & \frac{\partial^2\pi_r}{\partial e_m\partial e_r}\\ \frac{\partial^2\pi_r}{\partial e_r\partial p} & \frac{\partial^2\pi_r}{\partial e_r\partial\theta} & \frac{\partial^2\pi_r}{\partial e_r\partial e_m} & \frac{\partial^2\pi_r}{\partial e_r^2}\end{bmatrix}=\begin{bmatrix}-4b & \gamma_1+\gamma_2 & \beta_1-\beta_2 & \beta_1-\beta_2\\ \gamma_1+\gamma_2 & -\eta & 0 & 0\\ \beta_1-\beta_2 & 0 & -\xi_1 & 0\\ \beta_1-\beta_2 & 0 & 0 & -\xi_2\end{bmatrix}. \tag{A.1}$$

Since $\frac{\partial^2\pi_r}{\partial\theta^2}=-\eta<0$,

$$\begin{bmatrix}-\eta & 0\\ 0 & -\xi_1\end{bmatrix}=\eta\xi_1>0, \tag{A.2}$$

and

$$\begin{bmatrix}-\eta & 0 & 0\\ 0 & -\xi_1 & 0\\ 0 & 0 & -\xi_2\end{bmatrix}=-\eta\xi_1\xi_2<0, \tag{A.3}$$

we can obtain π_c is strictly jointly concave in θ, e_m, and e_r.

However, due to $\frac{\partial^2\pi_r}{\partial p^2}=-4b<0$, and

$$\begin{bmatrix}-4b & \gamma_1+\gamma_2\\ \gamma_1+\gamma_2 & -\eta\end{bmatrix}=4b\eta-(\gamma_1+\gamma_2)^2, \tag{A.4}$$

the above equation may be negative for small enough b, so π_c is indefinite with respect to p and θ, and hence π_c is not jointly concave in p, θ, e_m, and e_r.

A.2. Proof of proposition 4.2

Proposition 4.1 shows that π_c has a unique optimal solution for any given p. Taking the first-order partial derivatives of π_c with respect to θ, e_m, and e_r, then letting the derivatives be zero, we have

$$\frac{\partial\pi_c}{\partial\theta}=(p-c)(\gamma_1+\gamma_2)-\eta\theta=0, \tag{A.5}$$

$$\frac{\partial\pi_c}{\partial e_m}=(p-c)(\beta_1-\beta_2)-\xi_1 e_m=0, \tag{A.6}$$

$$\frac{\partial\pi_c}{\partial e_r}=(p-c)(\beta_1-\beta_2)-\xi_2 e_r=0, \tag{A.7}$$

so $\theta_c(p)=\frac{(p-c)(\gamma_1+\gamma_2)}{\eta}$, $e_{mc}(p)=\frac{(p-c)(\beta_1-\beta_2)}{\xi_1}$, $e_{rc}=\frac{(p-c)(\beta_1-\beta_2)}{\xi_2}$. Lastly, Substituting (9)–(11) into (8) and simplifying, we obtain (12).

A.3. Proof of proposition 4.6

The Hessian matrix of π_m^d with respect to w, θ, and e_m is

$$H^{\pi_r}=\begin{bmatrix}\frac{\partial^2\pi_m^d}{\partial w^2} & \frac{\partial^2\pi_m^d}{\partial w\partial\theta} & \frac{\partial^2\pi_m^d}{\partial w\partial e_m}\\ \frac{\partial^2\pi_m^d}{\partial\theta\partial w} & \frac{\partial^2\pi_m^d}{\partial\theta^2} & \frac{\partial^2\pi_m^d}{\partial\theta\partial e_m}\\ \frac{\partial^2\pi_m^d}{\partial e_m\partial w} & \frac{\partial^2\pi_m^d}{\partial e_m\partial\theta} & \frac{\partial^2\pi_m^d}{\partial e_m^2}\end{bmatrix}=\begin{bmatrix}\frac{-2\beta_1^2}{\xi_2} & \gamma_2 & -\beta_2\\ \gamma_2 & -\eta & 0\\ -\beta_2 & 0 & -\xi_1\end{bmatrix}. \tag{A.8}$$

Hence, π_m^d is jointly concave in w, θ, and e$_m$ only if $\eta>\frac{\xi_1\xi_2\gamma_2^2}{2\xi_1\beta_1^2-\xi_2\beta_2^2}$. Thus the equilibrium decisions can be reached from solving $\frac{\partial\pi_m^d}{\partial w}=0$, $\frac{\partial\pi_m^d}{\partial\theta}=0$, and $\frac{\partial\pi_m^d}{\partial e_m}=0$.

A.4. Proof of proposition 4.8

Substituting (14)–(16) into expressions in Proposition 4.4 and simplifying, respectively, we get (17) and (18).

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