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International Conference on Electronic Business (ICEB)

Winter 12-4-2016

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ABSTRACT

In this paper, considering a cross-border e-retail supply chain composed by a foreign supplier and a cross-border e-retailer, we study the impact of different power structures on the supply chain members' pricing and profits by establishing foreign supplier Stackelberg (FSS), cross-border e-retailer Stackelberg (CES) and vertical Nash (VN) game model on the basis of discussing O2O dual-channel retail mode and pricing decision. The results show that: i) the cross-border e-retailer prefer to choose the centralized pricing mode and will gain more profit than that in the decentralized pricing mode under the condition of O2O dual-channel retailing. ii) The impact of Stackelberg game on dual channel pricing of the cross-border e-retailer is identical, but the impact of three games on foreign supplier's pricing is significant, (i.e., the wholesale price of the foreign supplier becomes smaller with the game dominance decreased gradually). iii) The impact of three games on cross-border electronic supply chain members' profits is significant (i.e., members' profits become smaller with the game dominance decreased gradually. In addition, the impact of Stackelberg game on supply chain total profits is identical. However, the supply chain total profits under Vertical Nash game are more than Stackelberg game.

Keywords: Dual-channel retailing, Stackelberg/Nash game, cross-border e-commerce, supply chain management.

INTRODUCTION

In recent years, along with the rapid implementation of a succession of policies, cross-border electronic commerce in China has got swift and violent development [1-2]. According to the China E-business Research Center (2016), only Hangzhou city, the size of its cross-border e-commerce transactions is $3.464 billion in 2015, export $2.273 billion and $1.191 billion of imports [3]. However, the impacts of lacking of physical product experience, waiting for a long time to pay and delivery and experiencing a complex refunding or changing on the customer's shopping experience are so serious. Under this background, the cross-border O2O dual-channel retail mode consist of physical offline retail channels and online channels becomes more and more popular, and then the decision issue is how to develop a pricing strategy in an O2O mixed dual-channel to maximize the cross-border e-retailer's benefits in the online and offline channels [4]. In addition, the different power structures between e-commerce giants, small, medium-sized e-retailers and foreign suppliers in the cross-border electronic supply chain result in the different bargaining power between them and foreign suppliers, which affect their pricing strategies and profits level.

Therefore, from the perspective of cross-border electronic supply chain, studying the impact of different power structures on dual-channel pricing of cross-border e-retailers and supply chain members' profits is an interesting issue. As a consequence, we assume that there are three supply chain power structures which are foreign supplier Stackelberg (FSS) (power structure 1), cross-border e-retailer Stackelberg (CES) (power structure 2) and Vertical Nash (VN) game model (power structure 3) in a cross-border electronic supply chain composed of a foreign supplier and a cross-border e-retailer with O2O dual channel. We firstly build demand models by comparing the consumer surplus and discuss the pricing decision problem. Then on this basis, we analyze the impact of different power structures of supply chain on the supply chain members' pricing and profits by comparing the sales prices and profits under three supply chain power structures. The results show that i) Cross-border e-retailer should implement the centralized pricing strategy comparing with the decentralized pricing decisions under the condition of O2O dual-channel retailing. ii) The impact of Stackelberg game on dual channel pricing of the cross-border e-retailer is identical, but the impact of three games on foreign supplier's pricing is significant (i.e., the wholesale price of the foreign supplier becomes smaller with the game dominance decreased gradually). iii) The impact of three games on cross-border electronic supply chain members' profits is significant (i.e., members' profits become smaller with the game dominance decreased gradually. In addition, the impact of Stackelberg game on supply chain total profits is identical. However, the supply chain total profits under Vertical Nash game are more than Stackelberg game.

The remainder of this article is organized as follows. In Section 2, we make a brief review of relevant literature. In Section 3, we provide a model description and problem statement. In Section 4, we analyze the two pricing modes, centralized pricing and decentralized pricing. In section 5, we discuss the pricing strategies in FSS model, CES model, and VN model respectively. In Section 6, the impact of different power structures on pricing decisions and cross-border electronic supply chain profits in an O2O dual-channel is discussed. Finally, conclusions and managerial insights are presented in Section 7.

LITERATURE REVIEW

The literature related to this paper mainly includes the following two aspects: on the one hand, it is related research about O2O channel mode selection, on the other hand, it is the study of how supply chain member's relative power effect on the member pricing and profit.

O2O Dual-channel Selection

Among many studies of O2O dual-channel selection, the researchers initially studied the operation mode of the O2O and its impact on traditional business model [5-7] based on O2O initial definition Online - Offline (Online to Offline) which is to bring online consumers into the traditional bricks-and-mortar stores. However, the O2O dual-channel in this study refers to the cross-border e-retailer sells product through online and offline sales channels. In this respect, the early investigators from the perspective of manufacturers studied the issue of whether manufacturers should self-built online direct sales channel based on the original retail channels [8-14], their researches show that self-built new online direct sales channels for manufacturers are advantageous, in which Kumar et al [15] study the causes and mechanism that the original manufacturers add online direct sales channel based on traditional retail from the perspective of strategy. However, Yoo and Lee [16] pointed out that the introduction of direct sales channels does not always lead to lower retail prices and increase consumer welfare, and even in certain market conditions may lead to the deterioration of independent retailers' income.

The above researches only considered the price factors, through comparing the profits before and after building the online direct sales channel, and determined whether to introduce online direct marketing channels or not. Hill et al [17-21] made the delivery time decoupled from the service level, and assimilated the delivery time of online direct marketing channels into the model development to study the dual channel decision problem of manufacturer by comparing consumer surplus between two channels and building demand functions. In addition, Chen et al [22] studied dual channel strategy selection problem of manufacturers based on different levels of service between channels, pointed out the optimal channel decisions depending on operating costs of direct sales channels, inconvenience of buying from the entity shops and goods' characteristics and other factors.

Analysis shows that the above studies mostly from the perspective of manufacturer study the issue of dual channels decision and rarely analyze the issue from the perspective of retailers considering the impact of power structure of supply chain on member's decisions.

The Impact of Power Structure of Supply Chain on the Members' Pricing and Profits

Gaski et al [23-25] examined the impact of the power structure of the supply chain on the pricing and revenue of the members. In recent years, with the rapid development of network technology and logistics delivery, some manufacturers began to use online direct channel and traditional retail channel to sell goods. In this business environment, exploring the impact of different power structures of supply chain on members' pricing and profits has become the focus concerned by operations management and marketing scholars. Cai et al. [26-29] used supplier Stackelberg, retailer Stackelberg and vertical Nash game to model three different supply chain power structures and analyzed the impact of different power structures of supply chain on members' pricing and profits. These studies are based on background that manufacturers add online direct marketing channels and form dual- channel supply chain structure. However, Chen et al. [30] studied the impact of different power structures on members' pricing and profits from the perspective of retailer who owned online channel and offline channel. On the basis of comparative analysis of [30], Huang et al. [31] analyzed the effects of different power structures on members' pricing and benefits of two types of dual-channel supply chain, in which manufacturer owned the dual-channel or retailer owned the dual-channel. In addition, Lin et al [32] used manufacturer Stackelberg and retailer Stackelberg to establish pricing model of closed-loop supply chain with two channels, research and compare the impact of different power structure of closed-loop supply chain on members' pricing and revenue.

In summary, most existing literature study the operation and management of dual channels, and the impact of different power structures on members' pricing and profits from the perspective of manufacturer who establishes online direct channel. Few literatures study the impact of different power structures on members' pricing and profits from the perspective of retailer, especially cross-border e-retailer who owns on-line and off-line channels. Only Chen et al. [30] studied the similar problem, but the two deterministic linear demand functions of channels are given in that paper, which cannot reflect the essence of the customer channel choice. In this paper, from the perspective of the consumer surplus, we build dual channels demand function and benefit function to research dual channel pricing strategy problem of cross-border e-retailer with offline and online channels, meanwhile, analyze the impact of different power structures on members' pricing and benefits by comparing the price and profits.

PROBLEM DESCRIPTION AND ASSUMPTIONS

A foreign supplier and a cross-border e-retailer in our study form a two-echelon cross-border e-retail supply chain. The foreign supplier supplies product for the cross-border e-retailer and the cross-border e-retailer sells the product to the consumers through O2O channels that include both offline channel and online channel. We use c and w to denote foreign supplier's unit product cost and unit wholesale price, where $w > c$. We use p_1 and c_1 to denote offline unit retail price and offline unit sale cost. Similarly, p_2 is the online retail price and c_2 is the online unit sale cost. $p_i > w + c_i$ ($i = 1, 2$). Without loss of generality, we assume that $c_1 > c_2$.

The online channel only could use text, graphics, or symbols in a paper or web page catalog to describe the product for consumers virtually. Consumers can not touch, taste, smell the products before purchase them, and make evaluation mistakes. Even if the product may be returned after a mistaken purchase, the refund is typically only partial, therefore reducing the expectation of consumption value [33]. When consumers purchase from online channel, typically they need to wait several days for delivery and will be charged a shipping and handling fee [34]. Therefore, we use μ represent the customer acceptance of the online channel. According to Chiang et al. [9], when consumers purchase from online channel, they will have a less consumption value (alternatively called "willingness to pay") for the identical product purchased through offline channel. An empirical study by Liang and Huang [35] shows that overall, consumers prefer offline channel more than the online channels. Another recent survey by Kacen et al [36] Provides further evidence (Please see Table1) that the customer acceptance of online purchases is less than one for many product categories. Hence, the model in this paper is developed for those products with $0 < \mu < 1$.

Table 1: Customers' Acceptance Index μ for Online Channel

Category	Book	Shoes	Toothpaste	DVD player	Flowers	Food items
Acceptance	0.904	0.769	0.886	0.787	0.792	0.784

Note: the above values come from the study of Kacen et al. [36].

Following the model development in [9, 37-38], we assume that consumers have heterogeneous consumption value v. Thus, we assume that v is uniformly distributed within the consumer population from 0 to 1, with a density of 1. Therefore, the consumer surplus through the offline channel would be $v - p_1$. Due to $0 < \mu < 1$, the consumption value of consumers when the product is purchased through an online channel would be less than v. Therefore, the consumption value of the product when it is obtained from the online channel is μv, and then the resulting consumer surplus is $\mu v - p_2$. According to the theory of consumer's surplus, when $v - p_1 \geq 0$, all consumers will consider buying through the offline channel. The marginal consumer whose consumption value v_1 equals p_1 is indifferent to buying from through the offline channel. Similarly, when $\mu v - p_2 \geq 0$, all consumers will consider buying through the online channel. The marginal consumer whose consumption value v_2 equals p_2/μ is indifferent to buying from through the online channel. Under the O2O dual-channel retail environment, consumers are strategic, i.e., their purchase decisions are based on consumer surplus maximization. They would prefer the channel where they derive more surpluses. Thus consumers will compare the consumer surplus derived through the offline channel with the consumer surplus derived through the online channel (i.e., $v - p_1$ versus $\mu v - p_2$). If $v - p_1 > \mu v - p_2$, consumer would like to buy from the offline channel because consumer can derive more surpluses from the offline channel. If $\mu v - p_2 > v - p_1$, consumer would like to buy from the online channel because consumer can derive more surpluses from the online channel. If $\mu v - p_2 = v - p_1$ (i.e., $v_{12} = \frac{p_1 - p_2}{1 - \mu}$), the consumer would be indifferent to buying from either the offline channel or the online channel because consumer derives equal surplus from either channel. By comparing different consumption values (i.e., v_1, v_2 and v_{12}), we can show that when $v_1 > v_2$ (i.e., $p_1 > \frac{p_2}{\mu}$), then $v_{12} > v_1 > v_2$, all consumers with consumption value in the interval $[v_2, v_{12}]$ prefer to buy from the online channel, and all those in the interval $[v_{12}, 1]$ prefer to buy from the offline channel. Consumers whose consumption values are found in $[0, v_2]$ will not buy the product from either channel. When $v_2 > v_1$ (i.e., $\frac{p_2}{\mu} > p_1$), then $v_2 > v_1 > v_{12}$, all consumers would buy from the offline channel. Hence, we only consider the case where $p_1 > \frac{p_2}{\mu}$ and dual channels co-exist. Through above analysis, O2O dual-channel demand functions can be written as

$$d_1 = 1 - \frac{p_1 - p_2}{1 - \mu} \tag{1}$$

$$d_2 = \frac{p_1 - p_2}{1 - \mu} - \frac{p_2}{\mu} \tag{2}$$

Where d_1 and d_2 denote the demands of the offline and online channels, respectively.

In addition, we assume that all the demand and cost information is the common knowledge for both cross-border e-retailer and the foreign supplier. The cross-border e-retailer and the foreign supplier are rational and self-interested and aim to maximize their own profit. Figure 1 displays the model.

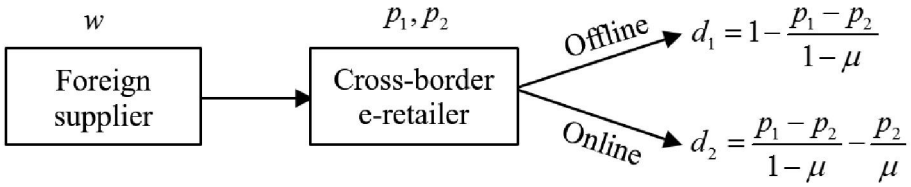

Figure 1: The model illustration of O2O dual- channel retail of cross-border e-retailer.

DUAL-CHANNEL PRICING STRATEGY CHOICE OF CROSS-BORDER E-RETAILER

The cross-border e-retailer has two pricing strategies: centralized pricing strategy and decentralized pricing strategy. Centralized pricing strategy refers that the cross-border e-retailer takes the centralized pricing strategies for both offline and online channels. While decentralized pricing strategy refers that the cross-border e-retailer takes the pricing strategies separately for offline and online channels.

Centralized Pricing Strategy

As to the centralized pricing strategy, the objective of cross-border e-retailer is to maximize the total profit of offline and online channels. In this case, the cross-border e-retailer's profit from two channels can be denoted as follows:

$$\pi_r = (p_1 - w - c_1)d_1 + (p_2 - w - c_2)d_2 \quad (3)$$

After substituting Eqs. (1) and (2) into Eq. (3), we have

$$\pi_r = (p_1 - w - c_1)(1 - \frac{p_1 - p_2}{1-\mu}) + (p_2 - w - c_2)(\frac{p_1 - p_2}{1-\mu} - \frac{p_2}{\mu}) \quad (4)$$

From Eq. (4) we can see: online channel price p_1 both has positive and negative influence on cross-border e-retailer's profit; offline channel price p_2 both has positive and negative influence on cross-border e-retailer's profit too; so the optimal online and offline prices are exist under certain conditions. As to the cross-border e-retailer's optimal price for offline channel (p_1^{i*}) and online channel (p_2^{i*}) in the centralized pricing strategy, we can obtain the following lemma.

Lemma1: the cross-border e-retailer's optimal prices for offline channel and online channel in the centralized pricing mode are:

$$p_1^{i*} = \frac{1 + w + c_1}{2}$$

$$p_2^{i*} = \frac{\mu + w + c_2}{2}$$

Proof. According to the principle of profit maximization, taking the first order derivatives and second order derivatives of Eq. (4) with respect to p_1 and p_2 , we find that

$$\frac{\partial \pi_r}{\partial p_1} = 1 - \frac{2p_1}{1-\mu} + \frac{2p_2}{1-\mu} + \frac{c_1 - c_2}{1-\mu}$$

$$\frac{\partial \pi_r}{\partial p_2} = \frac{2p_1}{1-\mu} - \frac{2p_2}{\mu(1-\mu)} + \frac{(1-\mu)w + c_2 - \mu c_1}{\mu(1-\mu)}$$

$$\frac{\partial^2 \pi_r}{\partial p_1^2} = -\frac{2}{1-\mu}$$

$$\frac{\partial^2 \pi_r}{\partial p_1 \partial p_2} = \frac{2}{1-\mu}$$

$$\frac{\partial^2 \pi_r}{\partial p_2^2} = -\frac{2}{\mu(1-\mu)}$$

$$\frac{\partial^2 \pi_r}{\partial p_2 \partial p_1} = \frac{2}{1-\mu}$$

The hessian matrix of π_r is as follows according to the profit function of the cross-border e-retailer:

$$\begin{bmatrix} -\frac{2}{1-\mu} & \frac{2}{1-\mu} \\ \frac{2}{1-\mu} & -\frac{2}{\mu(1-\mu)} \end{bmatrix}$$

Accordingly, the order principal minor determinants of the matrix are:

$$H_1 = -\frac{2}{1-\mu}, \quad H_2 = \frac{4}{\mu(1-\mu)}$$

Since $0 < \mu < 1$, as a result, $H_1 = -\frac{2}{1-\mu} < 0$, $H_2 = \frac{4}{\mu(1-\mu)} > 0$, therefore, the hessian matrix of π_r is a negative definite for all p_1 and p_2. The cross-border e-retailers' profit function with respect to p_1 and p_2 is a convex function in the centralized pricing mode, and the maximum value is unique. Let the first order derivations of Eq. (4) with respect to p_1 and p_2 equal to zero, we can get:

$$p_1 = \frac{2p_2 - \mu + c_1 - c_2 + 1}{2}$$

$$p_2 = \frac{2\mu p_1 + (1-\mu)w + c_2 - \mu c_1}{2}$$

Combining the two formulas above, we obtain the optimal retail p_1^{i*} and p_2^{i*}. This completes the proof. Accordingly, we can obtain the profit of cross-border e-retailer in the centralized pricing mode.

$$\pi_r(p_1^{i*}, p_2^{i*}) = \frac{(1-w-c_1)(1-\mu-c_1+c_2)}{4(1-\mu)} + \frac{(\mu-w-c_2)[\mu c_1 - c_2 - (1-\mu)w]}{4\mu(1-\mu)}$$

$$= \frac{\mu(1-\mu)[1-2c_1-2w] + w(1-\mu)(2c_2-w) + \mu c_1^2 + c_2^2 - 2\mu c_1 c_2}{4\mu(1-\mu)}$$

The Decentralized Pricing Strategy

The decentralized pricing strategy refers that the two channels are operated by different departments of the cross-border e-retailer, such as offline channel department and online channel department, and each department decides their channel retail price to maximize the profit. We define this scenario to be decentralized pricing strategy.

As to the decentralized pricing strategy, the offline channel's profit can be expressed as:

$$\pi_{r1} = (p_1 - w - c_1)d_1 \tag{4}$$

After substituting Eq. (1) into above Eq. (π_{r1}), we obtain the offline channel's profit of cross-border e-retailer as

$$\pi_{r1} = (p_1 - w - c_1)(1 - \frac{p_1 - p_2}{1-\mu}) \tag{5}$$

As to the decentralized pricing strategy, the online channel's profit can be expressed as:

$$\pi_{r2} = (p_2 - w - c_2)d_2$$

After substituting Eq. (2) into Eq. (π_{r2}) above, we obtain the online channel's profit of cross-border e-retailer as

$$\pi_{r2} = (p_2 - w - c_2)(\frac{p_1 - p_2}{1-\mu} - \frac{p_2}{\mu}) \tag{6}$$

After maximizing the profits of online and offline separately, we can obtain the following lemma2:

Lemma2: the cross-border e-retailer's optimal prices for offline channel and online channel in the decentralized pricing strategy are:

$$p_1^{d*} = \frac{2(1-\mu) + 3w + 2c_1 + c_2}{4-\mu}$$

$$p_2^{d*} = \frac{\mu(1-\mu) + (\mu+2)w + \mu c_1 + 2c_2}{4-\mu}$$

Proof. According to the principle of profit maximization, taking the first order derivatives and second order derivatives of Eq. (5) with respect to p_1 and taking the first order derivatives and second order derivatives of Eq. (6) with respect to p_2, we find that

$$\frac{\partial \pi_{r1}}{\partial p_1} = 1 - \frac{2p_1}{1-\mu} + \frac{p_2}{1-\mu} + \frac{w + c_1}{1-\mu}$$

$$\frac{\partial^2 \pi_{r1}}{\partial p_1^2} = -\frac{2}{1-\mu}$$

$$\frac{\partial \pi_{r2}}{\partial p_2} = \frac{p_1}{1-\mu} - \frac{2p_2}{\mu(1-\mu)} + \frac{w + c_2}{\mu(1-\mu)}$$

$$\frac{\partial^2 \pi_{r2}}{\partial p_2^2} = -\frac{2}{\mu(1-\mu)}$$

It can be seen that the second order derivative of π_{r1} with respect to p_1 is less than zero, therefore, π_{r1} is a convex function with respect to p_1 ; Similarly, π_{r2} is a convex function with respect to p_2 . Let the first order derivations of Eqs. (5) and (6) with respect to p_1 and p_2 equal to zero, we can get:

$$p_1 = \frac{1-\mu+p_2+w+c_1}{2}$$

$$p_2 = \frac{\mu p_1 + w + c_2}{2}$$

Combining the two formulas above, we obtain the optimal retail p_1^{d*} and p_2^{d*} .This completes the proof. Therefore, we can get the profit of cross-border e-retailers in the decentralized pricing mode.

$$\pi_r(p_1^{d*}, p_2^{d*}) = \frac{[(2-w)(1-\mu)-(2-\mu)c_1+c_2]^2}{(1-\mu)(4-\mu)^2} + \frac{[(1-\mu)(\mu-2w)+\mu(c_1+c_2)-2c_2]^2}{\mu(1-\mu)(4-\mu)^2}$$

According to the selection of cross-border e-retailer's pricing strategy, making a comparison of the maximum profits, the following proposition can be obtained.

Proposition 1:

$$\pi_r(p_1^{i*}, p_2^{i*}) > \pi_r(p_1^{d*}, p_2^{d*})$$

The proof of proposition 1 can be found in literature [30]. Not surprisingly, according to Proposition 1, we know that the cross-border e-retailer's profit which is obtained from the centralized pricing strategy is higher than that obtained from the decentralized pricing strategy. Therefore, the cross-border e-retailer prefers to take the centralized pricing strategy. Hereinafter, we assume that the cross-border e-retailer adopts the centralized pricing strategy.

THE PRICING AND PROFIT OF MEMBERS OF CROSS-BORDER E-COMMERCE SUPPLY CHAIN UNDER DIFFERENT POWER STRUCTURES

Foreign Supplier Stackelberg (FSS) Model

The main difference between various power structures is that the players make their decisions in sequence in the Stackleberg games whereas they make their decisions simultaneously in the Nash game [30]. In an FSS market, the sequence of events is as follows. Firstly, the cross-border e-retailer's reaction function is derived, and the cross-border e-retailer's offline and online retail price can be obtained which is denoted by the foreign supplier's wholesale price the foreign supplier announces the wholesale price to the cross-border e-retailer. Then, the manufacturer takes the cross-border e-retailer's reaction function into consideration to determine its wholesale price. Third, the foreign supplier selects her optimal wholesale price using the response function of the cross-border e-retailer so as to maximize her profit. Finally, when the consumer demand is realized, the foreign supplier and the cross-border e-retailer gain their revenues.

The foreign supplier's profit $\pi_s(w)$ in an FSS market can be denoted as:

$$\pi_s(w) = (w-c)d_1 + (w-c)d_2 \tag{7}$$

After substituting Eqs. (1) and (2)into Eq. (7) above, we obtain the foreign supplier's profit

$$\begin{aligned}\pi_s(w) &= (w-c)(1-\frac{p_1-p_2}{1-\mu}) + (w-c)(\frac{p_1-p_2}{1-\mu} - \frac{p_2}{\mu}) \\ &= (w-c)(1-\frac{p_2}{\mu})\end{aligned} \tag{8}$$

In the section 4.1 of this paper, we get $p_2^{i*} = \frac{\mu+w+c_2}{2}$. Now we substitute $p_2^{i*} = \frac{\mu+w+c_2}{2}$ into π_s and take the first order derivative of π_s with respect to w . Then, we make the first order derivative equal to 0 and obtain the proposition as below:

Proposition 2: In an FSS market, the wholesale price of the foreign supplier and the offline and online prices of cross-border e-retailer are as below:

$$w_s^* = \frac{\mu+c-c_2}{2}$$

$$p_1^{s*} = \frac{2+\mu+c+2c_1-c_2}{4}$$

$$p_2^{s*} = \frac{3\mu+c+c_2}{4}$$

From proposition 2 and Eq. (4), we get the cross-border e-retailer's maximum profit in an FSS market as

$$\pi_r(p_1^{s*}, p_2^{s*}) = \frac{(2-\mu-c-2c_1+c_2)(1-\mu-c_1+c_2)}{8(1-\mu)} + \frac{(\mu-c-c_2)[\mu^2-\mu+2\mu c_1-\mu c_2-(1-\mu)c-c_2]}{16\mu(1-\mu)} \tag{9}$$

From proposition 2 and Eq. (8), we get the foreign supplier's maximum profit in an FSS market as

$$\pi_s(w_s^*) = \frac{(\mu-c-c_2)^2}{8\mu} \tag{10}$$

From (9) and Eq. (10), we get the supply chain's profit in an FSS market, denoted $\pi(w_s^*, p_1^{s*}, p_2^{s*})$, as

$$\pi(w_s^*, p_1^{s*}, p_2^{s*}) = \pi_r(p_1^{s*}, p_2^{s*}) + \pi_s(w_s^*) \tag{11}$$

Cross-border E-retailer Stackelberg (CES) Model

In a CES market, the cross-border e-retailer and the foreign supplier make their decisions in sequence and the order of events is as follows. Firstly, the cross-border e-retailer announces her offline retail price and online retail price. Then, foreign supplier decides her wholesale price given the retailer's offline retail price and online retail price. Third, the cross-border e-retailer chooses her optimal offline retail price and online retail price using the response function of the supplier so as to maximize her profit. Finally, when the consumer demand is realized, the foreign supplier and the cross-border e-retailer gain their revenues.

We assume that the marginal profit of offline channel (denoted m_1) is $m_1 = p_1 - w$, the marginal profit of online channel (denoted m_2) is $m_2 = p_2 - w$. Then, the foreign supplier's profit, denoted $\pi_s(w)$, is

$$\pi_s(w) = (w-c)\left[1-\frac{(m_2+w)}{\mu}\right] \tag{12}$$

Taking the first order derivative of $\pi_s(w)$ with respect to w and making the first order derivative equal to zero, we find that

$$w = \frac{\mu+c-m_2}{2}$$

After substituting $m_2 = p_2 - w$ into the formula above, we get $w = \mu + c - p_2$. After substituting $w = \mu + c - p_2$ into Eq. (4), taking the first order derivatives of Eq. (4) with respect to p_1, p_2 separately and making the first order derivatives equal to 0. We get the proposition as below.

Proposition 3: In a CES market, the wholesale price of the foreign supplier and the offline and online prices of cross-border e-retailer are as below:

$$w_r^* = \frac{\mu+3c-c_2}{4}$$

$$p_1^{r*} = \frac{2+\mu+c+2c_1-c_2}{4}$$

$$p_2^{r*} = \frac{3\mu+c+c_2}{4}$$

From proposition 3 and Eq. (4), we get the cross-border e-retailer's maximum profit in a CES market as

$$\pi_r(p_1^{r*}, p_2^{r*}) = \frac{(1-c-c_1)(1-\mu-c_1+c_2)}{4(1-\mu)} + \frac{(\mu-c-c_2)[\mu^2-\mu+2\mu c_1-\mu c_2-(1-\mu)c-c_2]}{8\mu(1-\mu)} \tag{13}$$

From proposition 3 and Eq. (12), we get the foreign supplier's maximum profit in a CES market as

$$\pi_s(w_r^*) = \frac{(\mu-c-c_2)^2}{16\mu} \tag{14}$$

From (13) and Eq. (14), we get the supply chain's profit in a CES market, denoted $\pi(w_r^*, p_1^{r*}, p_2^{r*})$, as

$$\pi(w_r^*, p_1^{r*}, p_2^{r*}) = \pi_r(p_1^{r*}, p_2^{r*}) + \pi_s(w_r^*) \tag{15}$$

Vertical Nash (VN) Model

In a VN market, the cross-border e-retailer and the foreign supplier make their decisions simultaneously and the order of events is as follows. The cross-border e-retailer decides her offline retail price and online retail price to maximize her profit given the supplier's wholesale price, and the foreign supplier decides her wholesale price to maximize her profit given the cross-border e-retailer's offline retail price and online retail price. Finally, when the consumer demand is realized, the cross-border e-retailer and the foreign supplier gain their revenues.

We assume that the marginal profit of offline channel (denoted m_1) is $m_1 = p_1 - w$, the marginal profit of online channel (denoted m_2) is $m_2 = p_2 - w$. Then, the foreign supplier's profit, denoted $\pi_s(w)$, is

$$\pi_s(w) = (w-c)\left[1-\frac{(m_2+w)}{\mu}\right] \tag{16}$$

Taking the first order derivative of $\pi_s(w)$ with respect to w and making the first order derivative equal to zero, we have

$$w = \frac{\mu + c - m_2}{2}$$

After substituting $m_2 = p_2 - w$ into the formula above, we get $w = \mu + c - p_2$. In the section 4.1 of this paper, the offline and online prices of the cross-border e-retailer in the centralized pricing mode are as below:

$$p_1^{i*} = \frac{1+w+c_1}{2}$$

$$p_2^{i*} = \frac{\mu+w+c_2}{2}$$

After substituting $w = \mu + c - p_2$ into p_1^{i*}, p_2^{i*} above, we get the following proposition:

Proposition 4: In a VN market, the wholesale price of the foreign supplier and the offline and online prices of cross-border e-retailer are as below:

$$w_v^* = \frac{\mu + 2c - c_2}{3}$$

$$p_1^{v*} = \frac{3+\mu+2c+3c_1-c_2}{6}$$

$$p_2^{v*} = \frac{2\mu+c+c_2}{3}$$

From proposition 4 and Eq. (4), we get the cross-border e-retailer's maximum profit in a VN market as

$$\begin{aligned}\pi_r(p_1^{v*}, p_2^{v*}) = &\frac{(3-\mu-2c-3c_1+c_2)(1-\mu-c_1+c_2)}{12(1-\mu)} \\ &+\frac{(\mu-c-c_2)[\mu^2-\mu+3\mu c_1-\mu c_2-(1-\mu)2c-2c_2]}{18\mu(1-\mu)}\end{aligned} \tag{17}$$

From proposition 4 and Eq. (16), we get the foreign supplier's maximum profit in a VN market as

$$\pi_s(w_v^*) = \frac{(\mu-c-c_2)^2}{9\mu} \tag{18}$$

From (17) and Eq. (18), we get the supply chain's profit in a VN market, denoted $\pi(w_v^*, p_1^{v*}, p_2^{v*})$, as

$$\pi(w_v^*, p_1^{v*}, p_2^{v*}) = \pi_r(p_1^{v*}, p_2^{v*}) + \pi_s(w_v^*) \tag{19}$$

COMPARATIVE ANALYSIS

In this section, we discuss the impact of different power structures on the cross-border e-retail supply chain's decisions and performances. As to the impact of different power structures in the cross-border e-retail supply chain's optimal price, we can obtain the following proposition:

Proposition 5: $p_1^{s*} = p_1^{r*} > p_1^{v*}$, $p_2^{s*} = p_2^{r*} > p_2^{v*}$ and $w_s^* > w_v^* > w_r^*$

Proof. From propositions 2 and 3, we can obtain $p_1^{s*} = p_1^{r*}$ and $p_2^{s*} = p_2^{r*}$ directly. Since $w > c$, from propositions 2, 3 and 4, we get $\mu - c - c_2 > 0$. From propositions 3 and 4, we obtain $p_1^{r*} - p_1^{v*} = \frac{\mu-c-c_2}{12} > 0$ and $p_2^{r*} - p_2^{v*} = \frac{\mu-c-c_2}{12} > 0$, therefore, $p_1^{r*} > p_1^{v*}$ and $p_2^{r*} > p_2^{v*}$. Hence, $p_1^{s*} = p_1^{r*} > p_1^{v*}$ and $p_2^{s*} = p_2^{r*} > p_2^{v*}$. From propositions 2 and 4, we get $w_s^* - w_v^* = \frac{\mu-c-c_2}{6} > 0$, that is $w_s^* > w_v^*$. From propositions 3 and 4, we get $w_v^* - w_r^* = \frac{\mu-c-c_2}{12} > 0$, that is $w_v^* > w_r^*$. Therefore, $w_s^* > w_v^* > w_r^*$. This completes the proof.

According to proposition 5, we know that the cross-border e-retailer's optimal offline retail price and online retail price in an FSS market are equal to those in an CES market, that is, FSS or CES market structure has no effect on the cross-border e-retailer's retail prices. It means that the cross-border e-retailer with O2O mixed dual-channel has more flexibility in different

market structures. In addition, the cross-border e-retailer's optimal offline retail price and online retail price in an FSS and CES market are higher than those in a VN market. This means that consumers are generally better off in a VN power structure. This can be explained by the fact that when the foreign supplier and the cross-border e-retailer have a more balanced market power in a VN market, there is a more intense competition which drives the prices down. In addition, we also know that the foreign supplier's optimal wholesale price is more sensitive to the power structure as the foreign supplier's optimal wholesale price in an FSS market is the highest, the foreign supplier's optimal wholesale price in a CES market is the lowest, and the foreign supplier's optimal wholesale price in a VN market is in the middle. This means that the foreign supplier will set higher wholesale price when she has more market power, and set lower wholesale price when she has less market power.

Next, we discuss the impact of power structure on the cross-border e-retail supply chain's maximum profit; we can obtain the following proposition:

Proposition6: $\pi_r(p_1^{r*}, p_2^{r*}) > \pi_r(p_1^{v*}, p_2^{v*}) > \pi_r(p_1^{s*}, p_2^{s*})$, $\pi_s(w_s^*) > \pi_s(w_v^*) > \pi_s(w_r^*)$ And $\pi(w_v^*, p_1^{v*}, p_2^{v*}) > \pi(w_r^*, p_1^{r*}, p_2^{r*}) = \pi(w_s^*, p_1^{s*}, p_2^{s*})$

Proof. From (13) and (17), we get $\pi_r(p_1^{r*}, p_2^{r*}) - \pi_r(p_1^{v*}, p_2^{v*}) = \frac{(\mu - c - c_2)^2}{72\mu} > 0$, that is $\pi_r(p_1^{r*}, p_2^{r*}) > \pi_r(p_1^{v*}, p_2^{v*})$. From (17) and (9), we get $\pi_r(p_1^{v*}, p_2^{v*}) - \pi_r(p_1^{s*}, p_2^{s*}) = \frac{7(\mu - c - c_2)^2}{144\mu} > 0$, that is $\pi_r(p_1^{v*}, p_2^{v*}) > \pi_r(p_1^{s*}, p_2^{s*})$.

Hence, $\pi_r(p_1^{r*}, p_2^{r*}) > \pi_r(p_1^{v*}, p_2^{v*}) > \pi_r(p_1^{s*}, p_2^{s*})$. From (10), (14) and (18), we can directly get $\pi_s(w_s^*) > \pi_s(w_v^*) > \pi_s(w_r^*)$. From (11) and (15), we get $\pi(w_r^*, p_1^{r*}, p_2^{r*}) - \pi(w_s^*, p_1^{s*}, p_2^{s*}) = 0$, that is $\pi(w_r^*, p_1^{r*}, p_2^{r*}) = \pi(w_s^*, p_1^{s*}, p_2^{s*})$. From (19) and (15), we get $\pi(w_v^*, p_1^{v*}, p_2^{v*}) - \pi(w_s^*, p_1^{s*}, p_2^{s*}) = \frac{5(\mu - c - c_2)^2}{144\mu}$, that is $\pi(w_v^*, p_1^{v*}, p_2^{v*}) > \pi(w_s^*, p_1^{s*}, p_2^{s*})$.

Hence, $\pi(w_v^*, p_1^{v*}, p_2^{v*}) > \pi(w_r^*, p_1^{r*}, p_2^{r*}) = \pi(w_s^*, p_1^{s*}, p_2^{s*})$. This completes the proof.

According to proposition 6, we know that the cross-border e-retailer's profit in a CES market is the highest; the retailer's profit in an FSS market is the lowest; and the cross-border e-retailer's profit in a VN market is the middle. In contrast, the foreign supplier's profit in a CES market is the lowest; the foreign supplier's profit in an FSS market in the highest; and the foreign supplier's profit in a VN market is in the middle. This means that both the foreign supplier and the cross-border e-retailer will gain more profit when they are the more dominant player in the supply chain. From the view of the whole supply chain, the optimal overall profit in a CES market is equal to that in an FSS market, but lower than that in a VN market. This means that, as a whole, the supply chain is more competitive and generates more profits if the cross-border e-retailer and the foreign supplier have equivalent market power. In this case, the competition turns into an opportunity, which improves the supply chain profitability.

CONCLUSIONS AND MANAGERIAL INSIGHTS

Conclusions

In this paper, we consider a cross-border e-retail supply chain composed by a foreign supplier and a cross-border e-retailer. The cross-border e-retailer orders products from the foreign supplier and sells to the end consumers through offline and online dual channels. We use the game theory to model the cross-border e-retail supply chain with O2O mixed dual channels and obtain many interesting results. The analysis results show that: i) the cross-border e-retailer prefers to choose the centralized pricing mode and will gain more profit than that in the decentralized pricing mode; ii) the supply chain power structure has noticeable effect on the cross-border e-retail supply chain's pricing decisions and performance. In a VN market, the market competition is more intense and the cross-border e-retailer will set lower retail prices than those in an FSS or a CES market. The foreign supplier will set higher wholesale price when she has more market power. In contrast, she will set a lower wholesale price when she has less market power. Both the foreign supplier and the cross-border e-retailer will gain more profit when they have more market power, but the entire supply chain will gain greater profit when the foreign supplier and the cross-border e-retailer have a more balanced power distribution.

Managerial Insights

The managerial insights of this paper are as follows: i) from the perspective of pricing, offline store and online channel of cross-board e-retailers should implement centralized price mode instead of pricing by two independent operating departments separately; ii) under the condition of monopoly, no matter cross-border e-retailers stay at advantages or disadvantages in a Stackelberg game, they can adopt identical online and offline prices, but they should make compromise in VN market to prevent foreign suppliers seeking other cross-border for cooperation; iii) from the perspective of profit, if the cross-border e-retailers stay at a more advantageous position in the competition with foreign suppliers, they will obtain more profits. Therefore, cross-border e-retailers should strive to obtain and maintain their competitive advantages. In addition, it is a challenging and meaningful research direction to integrate the service level into the demand model development.

ACKNOWLEDGEMENTS

This research is supported by National Natural Science Foundation of China (Nos.71471025, 71171029).

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