Cao, B, Dubey, R and Luo, Z

Examining B2B channel decision-making within differential quality-level zone: a supply chain design using a non-cooperative strategic game theoretic approach ("Stackelberg Supply Chain for B2B")

Examining B2B Channel Decision-making within Differential Quality-level Zone: A supply chain design using a non-cooperative strategic game theoretic approach

(“**Stackelberg Supply Chain for B2B**”)

Abstract:

Purpose - The consumers want to purchase the target products in the right place, while the manufacturers want to allocate their own possible products to optimal distribution channels. The manufacturer must know how to handle itself in this business. The purpose of the study is to examine the B2B channel decision-making with different product qualities in a non-cooperative supply chain.

Design/methodology/approach - We develop a B2B Manufacturer-Stackelberg game as an analytical framework, combining asymmetric preference of purchase channels choice by the consumers, a continuous quality setting of the manufacturer, and differential channel structure to study the manufacturer’s product strategy and channel optimization. By horizontal comparisons across four channel structures, product variety can be classified into the differential quality-level zone through exogenous quality intervention, and the preference of manufacturers in each quality-level zone within the structures can be ranked.

Findings - Theoretically and practically, the hybrid-channel structure should be completely neglected when the direct channel is dominant over the retail channel. In contrast, dual-channel structures dominate single channels irrespective of the channel power, and channel preferences between high-quality and low-quality zones are stable while the preference in medium-quality zone is unstable. In addition, the supply chain system cannot achieve global Pareto improvement without any additional coordination mechanism between the manufacturer and the retailer.

Originality/value - The extended results by numerical examples suggest that the bigger the area of the medium-quality zone, the more significant the product variety of the manufacturer.

Keywords: *Asymmetric preference, quality threshold, channel decision-making, non-cooperative game analysis, B2B Manufacturer-Stackelberg supply chain*

1. Introduction

Purchase channels chosen by the consumers are not an unfamiliar concept in ordinary daily life (Kolbe *et al.*, 2022). Especially, digital business or economy has influenced human life greatly and is challenging traditional buying options, and the competition in channels is even increasingly fiercer (Hayes and Kelliher, 2022). To address this challenge, the manufacturers, but not limited to that, face a channel distribution decision of whether to add a new retailing channel to their existing offline channels. For example, JOOR is one of the leading international B2B digital wholesale platforms that connects brands and retailers to streamline their businesses. JOOR has over 14000 brands (based on the JOOR webpage at the time of writing), and several top retailers on the platform. What are the rationales behind such decisions of transition? In fact, purchase channel choice by the consumers directly affects channel decision-making by the manufacturers. On the other hand, whether traditional channels or online channels, a crucial aspect mainly depends on the ownership of the channel rather than the channel's appearance.

As is well-known, Nokia Corporation had once been one of the best mobile brands. While the smartphone has been the popular tendency of the mobile phone market, Nokia overlooked this fact, and thus it has been gradually eliminated by the market. However, Apple and Samsung Corporations take full advantage of this trend continuously developing new types of smartphones and expanding online retailing channels to complement their existing channels, which makes these two corporations become the most popular brands and the most important manufacturers in the mobile phone market. In brief, the smartphone is the symbol mark of the quality of mobile phones. Especially, manufacturers should view online product reviews which as one of the major components of product quality when it comes to online shopping.

Additionally, product strategy is one of the other major components of the manufacturer when purchase channels chosen by the consumers is taken place, and it has a significant impact on the production decision of product variety or not. If the manufacturer prefers product variety, the key question is how to define the differential product (e.g., high-quality, low-quality, other-quality, etc.) when the continuous quality variable is introduced, the most commonly including different brands (e.g., *Procter & Gamble*) and different series of the same brand (e.g., *most electronics companies*).

Furthermore, how quality intervention can help to better optimize channel performance when making decisions by the manufacturer is another key question. For example, Eureka Forbes Ltd. sells its premium brand vacuum cleaners directly while selling its base models through retail channels (Sridharan *et al.*, 2012). Combining distribution channels and product strategy, a supply chain system is highly important in making decisions for both manufacturers and consumers. Because commercial competition not only involves competition between enterprises but also competition between supply chains.

This study mainly attempts to analyze two streams of literature: *channel structure* (Bian *et al.*, 2015; Hotkar *et al.*, 2021; Li *et al.*, 2018; Wang *et al.*, 2020) and *product quality* (Ferrer *et al.*, 2010; Kalnins *et al.*, 2016; Qi *et al.*, 2016; Zhang *et al.*, 2019a, b). Cao et al. (2022) in one of the recent studies have attempted to examine the effects of product quality, promotional effort, and hybrid channels on the whole supply chain performance in four types of dual-channel structures. Chen et al. (2017) further demonstrate that the quality can be improved irrespective of supply chain design by adding a new channel. The design of the distribution channels in the supply chain is often considered complex. For instance, in one of the studies He et al. (2022), developed analytical models to demonstrate the supplier's choice for the distribution supply chain, in which the retailers often dominate over the suppliers due to their significant impact on sales which leads to a non-cooperative game. The literature demonstrates the interaction among product, pricing, and channel decision-making in the traditional supply chain (Choi 1991, 1996; Huang *et al.*, 2018; Wang *et al.*, 2017; Yan *et al.*, 2018).

Practically, digital business has influenced ordinary daily life greatly and is challenging the traditional sales model, such as online channels. This not only significantly changes the purchase habit and behavior of the consumer, but also inevitably competes with offline channels, even though this competition is increasingly more aggressive. Chen et al. (2017) developed a model of a dual-channel structure to determine when a retailer should introduce an online channel. Hu et al. (2021) considered three power structures to characterize the channel integration strategy for online retailers. The impact of online channels on supply chain systems, and the phenomenon of competition and conflicts has gained significant traction from the academic community (see, Shen *et al.*, 2017; Shi *et al.*, 2020).

However, management experts are quite optimistic about the seamless, retail world where consumers can shop across channels, anywhere, and at any time (Beck *et al.*, 2015), which suggests cooperative behavior rather than competition and conflict among all types of distribution channels. This retailing is often referred to as omnichannel retailing and has gained significant momentum in recent years following rapid growth in digitalization (Alonso-Garcia *et al.*, 2022). Cao et al. (2016) studied the impact of an *"online-to-store"* channel on the demand allocations and profitability of a retailer that considers multiple distribution channels. So far, there has been a large volume of literature focused on omnichannel retailing across consumer value-adding journeys, such as material flow, information flow, financing flow, etc. (see, Gao *et al.*, 2017; Saghiri *et al.*, 2017; Wu *et al.*, 2020).

The previous studies on product quality and channel structure mostly focused on how to distribute the discrete products in one kind of fixed channel structure, considering the commonly observed case where the indirect channel sells standard products whereas the direct channel offers custom products (see, Xiao *et al.*, 2014). In contrast, we rethink and reconstruct the product-channel model to examine the robustness and sensitivity of channel decision-making to the homogeneity of the continuous quality variables. Moreover, this study continues to answer the following extended questions to fill this research gap:

***RQ1*: Does the dual-channel structure always an efficient way of improving the manufacturer's profit performance?**

***RQ2*: Can the supply chain system achieve coordination between the manufacturer and the retailer without any additional mechanism design?**

Taking aim at the above questions, we use quality intervention to solve the B2B Manufacturer-Stackelberg framework.

A manufacturer can distribute its products through a direct channel (i.e., who exclusively operates its own channel) or through a retail channel (i.e., who commonly cooperates with independent retailers). Considering the product with continuous quality setting and differential channel structure, firstly we propose four different types of supply chain structure as illustrated in Figure **1** and study the structures in any quality-level zone through quality threshold how to be ranked. The four different types of supply chain structure include two traditional single channels (direct channel and retailing channel)[1], hybrid-channel structure combining direct and retailing channels (i.e., R+D), and dual-retailer structure between two independent retailing channels (i.e., R+R), where two traditional single channels are viewed as benchmark cases to

[1] For simplicity, direct channel and retailing channel are abbreviated as **D** and **R**, respectively, in the following text.

horizontally compare with dual-channel structures, respectively.

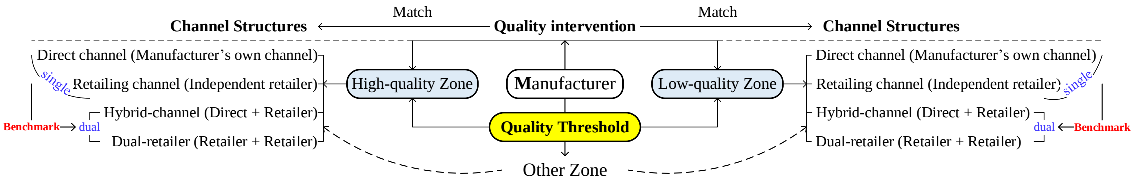

Fig. 1 The matching model considering quality intervention

Following the B2B Manufacturer-Stackelberg framework, a decision-making process must evolve into multiple stages as follows: in the first stage, in the estimation of production costs, the manufacturer fully takes into account the products in a given product strategy; in the second stage, the manufacturer compares and analyzes various possible types of channel structure based on the asymmetric preference of purchase channels choice by the consumers, while the retailer afterward based on whether or not complete information symmetry; last, but certainly not least, the optimal channel selection can be decided to match various possible quality-level zones of the manufacturer, which is the Pareto improvement. For the assumption of continuous quality setting, product quality is an exogenous variable (i.e., quality intervention as illustrated in Figure **1**) rather than a decision variable to solve and optimize the B2B Manufacturer-Stackelberg model throughout the paper.

The rest of this paper is organized as follows. Section **2** introduces four types of supply chain structure by considering a quality intervention, and channel decision-making within the differential quality-level zone is given. In section **3**, the proposed theoretical models' rationality is verified by using numerical simulations, and further discussions are synchronously given. Finally, the conclusions are presented in section **4**.

2. Underpinning Theory and Theoretical Model

The term *"quality"* referred to the level of some attribute (e.g., *grades of gasoline*, *speed of CPU*, *diamond clarity*) that all consumers prefer higher levels of the attribute (Mussa *et al.*, 1978). From a broader perspective, quality can be abstracted into heterogeneous preference, which is assumed to explain the complexity of real-world phenomena and the term *"heterogeneity"* refers to the variation in the level of other attributes, for example, Stole (1995) & Villas et al. (1999) reflected the consumer's horizontal preference, which could come from differences across firms in location or reputation, and therefore is independent of product quality. Hence, this study proposes that heterogeneity is defined as the asymmetric preference of purchase channels choice made by the consumers, which respectively makes **direct market demand** for the manufacturer (*m*) and the retailer (*r*) in any supply chain structure. Taking retailing channel **R** for example, because the manufacturer does not directly engage in the distribution of products, it is direct demand is zero; however, the total demand of the manufacturer will benefit from the retailer's effort who cooperates with it. Furthermore, each consumer's utility function of sales agent *i* (*m* or *r*) can be expressed as follows:

$$U_i\left(\theta,\ \alpha_i,\ p_i\right)=\theta\cdot\alpha_i-p_i,\ i=m,r, \tag{1}$$

where α_i denotes nominal demand of sales agent *i* when initial price (p_i) is zero, which reflects attraction from consumers to sales agent *i*. p_i is a selling price of the product which is determined by sales agent *i*. The term θ refers to consumers with respect to their willingness to pay for products purchased from sales agent *i*, which is assumed to be distributed uniformly over $(0,1)$. Undoubtedly, any consumer with nonnegative utility is a necessary condition for a successful transaction. At the initial stage of sales, assuming $p_i\to 0^+$ as an example, consumers prefer the direct channel to retailing channel to purchase the product when $\alpha_m>\alpha_r$, and vice versa. Based on above, demand function and pricing strategy can be solved in each channel structure (Figure **1**). Table **1** summarizes key parameters (the demand) and dynamic variables (the price) in our B2B Manufacturer-Stackelberg supply chain.

Table 1: Definitions for key parameters and dynamic variables

$D_{i\mid j},\ i=m,r,r_2,\ j=D,R,RD,RR$	represents direct market demand of sales agent *i* in supply chain structure *j*
w	represents the wholesale price for the existing retailer (*r*) which is charged by the manufacturer (*m*) in supply chain structures R & RD
p_m, p_r	represent selling prices of the product in the terminal market which are directly determined by the manufacturer (*m*) and the existing retailer (*r*) in supply chain structures D, R & DR
w_r, w_m	represent wholesale prices for the existing retailer (*r*) and the new retailer (r_2) which are simultaneously charged by the manufacturer (*m*) in the supply chain structure RR
p_r, p_m	represent selling prices of the product in the terminal market which are directly determined by the existing retailer (*r*) and the new retailer (r_2) in the supply chain structure RR

2.1. Demand Analysis

Demand functions of the product in each channel structure can be yielded by using probability distribution of θ in Equation (1).

In direct channel **D**, the manufacturer not only owns products but also sells all through its own exclusive channel, and thus

$$D_{m|D} = P\{U_m > 0\} = 1 - \frac{p_m}{\alpha_m},\ D_{r|D} = 0. \tag{2}$$

In retailing channel **R**, however, the manufacturer sells its own products through an independent retailer who wants to cooperate with it, and thus

$$D_{m|R} = 0,\ D_{r|R} = P\{U_r > 0\} = 1 - \frac{p_r}{\alpha_r}. \tag{3}$$

In hybrid-channel structure **RD**, there exists horizontal competition during sales when a retailing channel is brought or a direct channel is added by the manufacturer. Because of asymmetric preference, demand function in each channel is constrained by $\alpha_m \neq \alpha_r$ as illustrated in Figure **2**, and thus

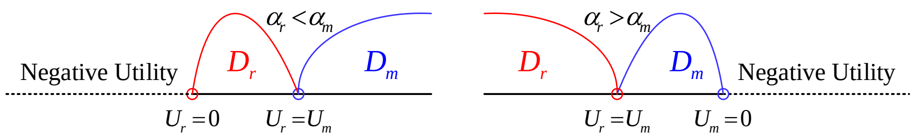

Fig. 2 Demand distribution in dual-channel under asymmetric preference

$$\begin{aligned}
&\text{I}.\ \alpha_m > \alpha_r \begin{cases} D_{m|RD} = P\{U_m > U_r\} = 1 - \frac{p_m - p_r}{\alpha_m - \alpha_r} \\ D_{r|RD} = P\{U_r > 0\} - P\{U_m > U_r\} = \frac{p_m - p_r}{\alpha_m - \alpha_r} - \frac{p_r}{\alpha_r} \end{cases} \\
&\text{II}.\ \alpha_m < \alpha_r \begin{cases} D_{m|RD} = P\{U_m > 0\} - P\{U_r > U_m\} = \frac{p_r - p_m}{\alpha_r - \alpha_m} - \frac{p_m}{\alpha_m} \\ D_{r|RD} = P\{U_r > U_m\} = 1 - \frac{p_r - p_m}{\alpha_r - \alpha_m} \end{cases}
\end{aligned}. \tag{4}$$

In dual-retailer structure **RR**, however, there similarly exists horizontal competition between two independent retailers during sales. Without loss of generality, we still utilize the same parameters α_m and p_m to represent nominal demand and selling price of the new retailer r_2. In a similar way, demand functions are constrained by $\alpha_m \neq \alpha_r$ can be derived as follows:

$$\begin{aligned}
&\text{III}.\ \alpha_m < \alpha_r \begin{cases} D_{r|RR} = P\{U_r > U_m\} = 1 - \frac{p_r - p_m}{\alpha_r - \alpha_m} \\ D_{r_2|RR} = P\{U_m > 0\} - P\{U_r > U_m\} = \frac{p_r - p_m}{\alpha_r - \alpha_m} - \frac{p_m}{\alpha_m} \end{cases} \\
&\text{IV}.\ \alpha_m > \alpha_r \begin{cases} D_{r|RR} = P\{U_r > 0\} - P\{U_m > U_r\} = \frac{p_m - p_r}{\alpha_m - \alpha_r} - \frac{p_r}{\alpha_r} \\ D_{r_2|RR} = P\{U_m > U_r\} = 1 - \frac{p_m - p_r}{\alpha_m - \alpha_r} \end{cases}
\end{aligned}. \tag{5}$$

Any of the demand functions must be nonnegative is a necessary condition for pricing analysis next, such that $D_{i|j} \geq 0,\ i = m, r, r_2,\ j = D, R, RD, RR$.

2.2. Pricing Strategy

Initially, we denote parameters Π_m and Π_r as the manufacturer's profit and retailer's profit, respectively. At the same time, a manufacturer's unit production cost is considered that a quadratic function of the product with continuous quality (Shi *et al.*, 2013), such that $c = q^2$. Thus, the manufacturer's and retailer's profit functions in structures D, R and RD can be briefly written as follows:

$$\begin{cases} \Pi_m = D_r \cdot (w - c) + D_m \cdot (p_m - c) \\ \Pi_r = D_r \cdot (p_r - w) \end{cases}, \tag{6}$$

and the variable w denotes wholesale price, which is charged by the manufacturer. For effective analysis, some constraints must be imposed, such that $p_r \geq w \geq c \geq 0$ and $p_m \geq c \geq 0$. Following the above structures D, R and RD, a two-stage dynamic game exists, e.g., the manufacturer first move and the retailer afterwards. In the first stage, the manufacturer charges a wholesale price (w) from an independent retailer. Next, the retailer selects its selling price (p_r) in a retailing channel and the manufacturer synchronously decides its selling price (p_m) in its own channel, respectively. We solved the game throughout backward induction, and the sequential game timing rule as follows:

$$\begin{cases} \dfrac{\partial \Pi_m}{\partial p_m} = 0 \\ \dfrac{\partial \Pi_r}{\partial p_r} = 0 \end{cases} \Rightarrow \frac{\partial \Pi_m}{\partial w} = 0,$$

the optimal solutions for wholesale price and selling prices with continuous quality are then calculated and listed in Table **2**.

Table 2: Optimal solutions for decision variables in structures D, R and RD

	D	**R**	Hybrid-channel **RD**	
			$\alpha_m > \alpha_r$	$\alpha_m < \alpha_r$
w^*	0	$\frac{\alpha_r + q^2}{2}$	$\frac{\alpha_r}{2} + \frac{(2\alpha_m + \alpha_r)(4\alpha_m - \alpha_r)}{2\alpha_m(8\alpha_m + \alpha_r)} \cdot q^2$	$\frac{\alpha_m^2 + 8\alpha_r^2}{2(\alpha_m + 8\alpha_r)} + \frac{q^2}{2}$
p_m^*	$\frac{\alpha_m + q^2}{2}$	0	$\frac{\alpha_m}{2} + \frac{6\alpha_m + 3\alpha_r}{2(8\alpha_m + \alpha_r)} \cdot q^2$	$\frac{\alpha_m(10\alpha_r - \alpha_m)}{2(\alpha_m + 8\alpha_r)} + \frac{q^2}{2}$
p_r^*	0	$\frac{3\alpha_r + q^2}{4}$	$\frac{\alpha_r}{2} + \frac{(2\alpha_m + \alpha_r)^2}{2\alpha_m(8\alpha_m + \alpha_r)} \cdot q^2$	$\frac{12\alpha_r^2 - 2\alpha_r\alpha_m - \alpha_m^2}{2(\alpha_m + 8\alpha_r)} + \frac{q^2}{2}$

In the same premise conditions, dual-retailer structure differs from the three structures, because there not only exist two independent and competitive retailers but also exist two static pricing games. Thus, the manufacturer's and retailer's profit functions in this structure can be briefly written as follows:

$$\begin{cases} \Pi_m = D_r \cdot (w_r - c) + D_{r2} \cdot (w_m - c) \\ \Pi_r = D_r \cdot (p_r - w_r) \\ \Pi_{r2} = D_{r2} \cdot (p_m - w_m) \end{cases}, \tag{7}$$

where w_r and p_r describe wholesale price and selling price of the existing retailer, meanwhile, w_m and p_m describe wholesale price and selling price of the new retailer. For effective analysis, some constraints also must be imposed, such that $p_r \geq w_r \geq c \geq 0$ and

$p_m \geq w_m \geq c \geq 0$. Similarly, a two-stage dynamic game also exists. In the first stage, the manufacturer respectively charges the wholesale prices (w_r & w_m) from the two independent retailers, and it is the first static pricing game. Next, the existing retailer selects its selling price (p_r) and the new retailer synchronously selects its selling price (p_m) from the end consumers, respectively, which is the second static pricing game. It is to continue to apply backward induction to solve this game, and the sequential game timing rule as follows:

$$\begin{cases} \dfrac{\partial \Pi_r}{\partial p_r} = 0 \\ \dfrac{\partial \Pi_{r2}}{\partial p_m} = 0 \end{cases} \Rightarrow \begin{cases} \dfrac{\partial \Pi_m}{\partial w_r} = 0 \\ \dfrac{\partial \Pi_m}{\partial w_m} = 0 \end{cases},$$

the optimal solutions for wholesale prices and selling prices with continuous quality are then calculated and listed in Table **3**.

Table 3: Optimal solutions for decision variables in dual-retailer structure

		w_r	w_m	p_r	p_m
Dual-retailer **RR**	$\alpha_m < \alpha_r$	$\frac{\alpha_r + q^2}{2}$	$\frac{\alpha_m + q^2}{2}$	$\frac{3\alpha_r(2\alpha_r - \alpha_m)}{2(4\alpha_r - \alpha_m)} + \frac{3\alpha_r}{2(4\alpha_r - \alpha_m)} \cdot q^2$	$\frac{(5\alpha_r - 2\alpha_m)\alpha_m}{2(4\alpha_r - \alpha_m)} + \frac{2\alpha_r + \alpha_m}{2(4\alpha_r - \alpha_m)} \cdot q^2$
	$\alpha_m > \alpha_r$			$\frac{(5\alpha_m - 2\alpha_r)\alpha_r}{2(4\alpha_m - \alpha_r)} + \frac{2\alpha_m + \alpha_r}{2(4\alpha_m - \alpha_r)} \cdot q^2$	$\frac{3\alpha_m(2\alpha_m - \alpha_r)}{2(4\alpha_m - \alpha_r)} + \frac{3\alpha_m}{2(4\alpha_m - \alpha_r)} \cdot q^2$

Through the above analysis, we found that all the selling price, wholesale price and demand function in any channel structure relate to product quality though it is not a decision variable, such that $p_i = p(q^2), w_i = w(q^2), D_i = D(q^2)$. However, continuous quality is introduced as control variable in the following discussion. And thus, the manufacturer's profit function is equally connected with product quality, which can be calculated in any channel structure as follows:

$$\Pi_{m|D} = \frac{(\alpha_m - q^2)^2}{4\alpha_m}, \tag{8}$$

$$\Pi_{m|R} = \frac{(\alpha_r - q^2)^2}{8\alpha_r}, \tag{9}$$

$$\Pi_{m|RD} = \begin{cases} \dfrac{1}{4\alpha_m\alpha_r(8\alpha_m + \alpha_r)}\begin{bmatrix} (2\alpha_m + \alpha_r)^2 (q^2)^2 - 2\alpha_m\alpha_r(8\alpha_m + \alpha_r)(q^2) + \\ \alpha_m^2\alpha_r(8\alpha_m + \alpha_r) \end{bmatrix} & \text{if } \alpha_m > \alpha_r \\ \dfrac{1}{4\alpha_m(\alpha_m + 8\alpha_r)}\begin{bmatrix} (\alpha_m + 8\alpha_r)(q^2)^2 - 2\alpha_m(\alpha_m + 8\alpha_r)(q^2) + \\ \alpha_m(\alpha_m + 2\alpha_r)^2 \end{bmatrix} & \text{if } \alpha_m < \alpha_r \end{cases}, \tag{10}$$

$$\Pi_{m|RR} = \begin{cases} \dfrac{1}{4\alpha_r(4\alpha_m - \alpha_r)}\left[(2\alpha_m + \alpha_r)(q^2)^2 - 6\alpha_m\alpha_r(q^2) + \alpha_m\alpha_r(2\alpha_m + \alpha_r)\right] & \text{if } \alpha_m > \alpha_r \\ \dfrac{1}{4\alpha_m(4\alpha_r - \alpha_m)}\left[(2\alpha_r + \alpha_m)(q^2)^2 - 6\alpha_m\alpha_r(q^2) + \alpha_m\alpha_r(2\alpha_r + \alpha_m)\right] & \text{if } \alpha_m < \alpha_r \end{cases}. \tag{11}$$

This study aims to find out whether the quality intervention will have an impact on product variety, and how this intervention affects channel decision-making and supply chain efficiency.

2.3. Matching Model Between Product and Channel

How to optimize channel structure in each quality-level zone is the **Pareto improvement** of manufacturers. In section 2.1., there exists a necessary condition ($D_{i|j} \geq 0,\ i = m, r, r_2,\ j = D, R, RD, RR$) on demand function. Firstly, we analyze demand function structures on two types of single channel, and two constraints can be obtained by calculating, such that $q_D^2 \leq \alpha_m$ and $q_R^2 \leq \alpha_r$. Because of asymmetric preference (i.e., $\alpha_m \neq \alpha_r$), there a thorough classified discussion about demand function structures on two types of dual-channel structure is given.

In hybrid-channel RD, it can be concluded that $\begin{cases} D_m \geq 0 \\ D_r = \frac{p_m - p_r}{\alpha_m - \alpha_r} - \frac{p_r}{\alpha_r} = -\frac{2\alpha_m + \alpha_r}{\alpha_r(8\alpha_m + \alpha_r)} \cdot q^2 < 0 \end{cases}$ when $\alpha_m > \alpha_r$, but RD is failure results from negative demand of the retailer. When $\alpha_m < \alpha_r$, on the other hand, it can be concluded that $\begin{cases} D_m = \frac{3\alpha_r(10\alpha_r - \alpha_m)}{(8\alpha_r + \alpha_m)^2} + \frac{3\alpha_r}{\alpha_m(8\alpha_r + \alpha_m)} \cdot q^2 > 0 \\ D_r = \frac{2\alpha_r + \alpha_m}{8\alpha_r + \alpha_m} > 0 \end{cases}$, and the feasible region of quality is $q_{RD}^2 > 0$. In a similar way, the feasible region of quality in dual-retailer RR is $q_{RR}^2 \leq \min\left\{\frac{\alpha_r}{2}, \frac{\alpha_m}{2}\right\}$. Next, we used some horizontal comparisons to determine quality thresholds, further quality-level zones are given, last the optimal channel decisions in all quality-level zone are made by the manufacturer.

2.3.1. D versus R

In an ideal setting (e.g., $\alpha_m = \alpha_r$), the manufacturer's profit obviously benefits from the direct channel, because it eliminates the intermediary, which may cause a double marginalization problem. Undoubtedly, asymmetric preference of purchase channels choice by the consumers can reflect the real market. An interesting question is whether the comparative advantage of direct channel can be maintained when compared with a retailing channel.

Theorem 1 If $1 < \Omega < 2$, a relative high quality-level zone (i.e., $\frac{\sqrt{\alpha_m \alpha_r}(\sqrt{2\alpha_m} - \sqrt{\alpha_r})}{\sqrt{2\alpha_r} - \sqrt{\alpha_m}} \leq q^2 \leq \min\{\alpha_m, \alpha_r\} = \alpha_m$) in R is superior to in D for the manufacturer's profit, while a relative low quality-level zone (i.e., $q^2 < \frac{\sqrt{\alpha_m \alpha_r}(\sqrt{2\alpha_m} - \sqrt{\alpha_r})}{\sqrt{2\alpha_r} - \sqrt{\alpha_m}}$) in R is inferior to in D. Any product distribution, on the other hand, in D absolutely outperforms in R if $\Omega < 1$.

Proof. By combining profit functions (8) and (9) under $\Omega \neq 1$, we can conclude as follows:

① Assuming $\alpha_m < \alpha_r$ and $\Pi_{m|D} > \Pi_{m|R}$ first, that is $q^2 < \frac{\sqrt{\alpha_m \alpha_r}(\sqrt{2\alpha_m} - \sqrt{\alpha_r})}{\sqrt{2\alpha_r} - \sqrt{\alpha_m}}$. To guarantee the nonnegativity of quality, assuming that $\Omega \equiv \alpha_r / \alpha_m$, which describes the relative channel power of a retailing channel over a direct channel at the initial stage of sales (e.g., $p_i \to 0^+$). Then, $\frac{\sqrt{\alpha_m \alpha_r}(\sqrt{2\alpha_m} - \sqrt{\alpha_r})}{\sqrt{2\alpha_r} - \sqrt{\alpha_m}}$ is a QT[2] value (QT$_1$) when $1 < \Omega < 2$. In contrast, $\Pi_{m|D} < \Pi_{m|R}$ when $q^2 > \frac{\sqrt{\alpha_m \alpha_r}(\sqrt{2\alpha_m} - \sqrt{\alpha_r})}{\sqrt{2\alpha_r} - \sqrt{\alpha_m}}$.

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[2] **QT** is the abbreviation of quality threshold.

② Assuming $\alpha_m > \alpha_r$ and $\alpha_m < 2\alpha_r$ (i.e., $\frac{1}{2} < \Omega < 1$), an increment in the manufacturer's profit can be computed as follows:

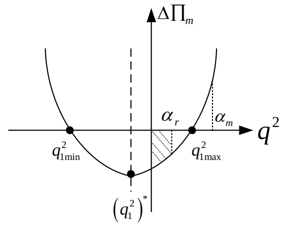
$$\Delta\Pi_m\left(q^2\right) = \Pi_{m|D} - \Pi_{m|R} = \frac{2\alpha_r\left(\alpha_m - q^2\right)^2 - \alpha_m\left(\alpha_r - q^2\right)^2}{8\alpha_m\alpha_r},$$

which indicates that $\Delta\Pi_{m|D\text{-}R}$ is always nonnegative, such that $\Pi_{m|D} > \Pi_{m|R}$.

③ Assuming $\alpha_m > \alpha_r$ and $\alpha_m > 2\alpha_r$ (i.e., $\Omega < \frac{1}{2}$), an increment in the manufacturer's profit can be viewed as the function of quality,

$$\Delta\Pi_m\left(q^2\right) = \Pi_{m|R} - \Pi_{m|D} = \frac{1}{8\alpha_m\alpha_r}\left[\left(\alpha_m - 2\alpha_r\right)\left(q^2\right)^2 + 2\alpha_m\alpha_r\left(q^2\right) - \alpha_m\alpha_r\left(2\alpha_m - \alpha_r\right)\right],$$

because the axis of symmetry is $(q_1^2)^* = -\frac{\alpha_m\alpha_r}{\alpha_m - 2\alpha_r} < 0$, we need to solve $\Delta\Pi_{m|R-D}\left(q^2\right) = 0$ and get its two roots like



$$q_{1\min}^2 = -\frac{\alpha_m\alpha_r + \left(\alpha_m - \alpha_r\right)\sqrt{2\alpha_m\alpha_r}}{\alpha_m - 2\alpha_r},\quad q_{1\max}^2 = \frac{\sqrt{\alpha_m\alpha_r}\left(\sqrt{2\alpha_m} + \sqrt{\alpha_r}\right)}{\sqrt{\alpha_m} + \sqrt{2\alpha_r}},$$

furthermore, $\alpha_r < q_{1\max}^2 < \alpha_m$, and thus, $\Delta\Pi_{m|R-D}$ is negative when $q^2 \in \left(0, \alpha_r\right]$ (see shaded part in right schematic diagram). Combining the results ② and ③, $\Pi_{m|D} > \Pi_{m|R}$ is always correct when $\Omega < 1$, such that $\alpha_m > \alpha_r$.

Theorem 1 breaks an intuitive cognition under appropriate condition, e.g., a retailing channel is matched with a relative high quality-level zone. In contrast, the manufacturer prefers a direct channel to distribute its own products belong to the feasible region of quality. Taking international marketing for example, both domestic and international markets compare to direct and retailing channels, respectively; which indicates that sales on the domestic market is a dominant strategy for the manufacturer from **Theorem 1**. But in practice, *"double standard"* of quality generally exists in the manufacturers. For example, CHAQICAIYE in China exported high-quality pickled cabbage through standardized production, whereas supplied shoddy pickled cabbage for domestic sales, the result is that it is in danger of losing its partners even withdraw from the market.

2.3.2. D versus RD

Theorem 2 For the manufacturer, any product distribution in RD absolutely outperforms in D as long as $1 < \Omega$.

Proof. By combining profit functions (8) and (10) under $1 < \Omega$, an incremental function in the manufacturer's profit is $\Delta\Pi_m = \Pi_{m|RD} - \Pi_{m|D} = \frac{\alpha_r(\alpha_r - \alpha_m)}{8\alpha_r + \alpha_m} > 0$, and thus, $\forall q^2 \in \left(0, \alpha_m\right]$ $\exists\,\Pi_{m|RD} > \Pi_{m|D}$.

Once the product penetration of any manufacturer reached saturation in domestic demand, exportation has been a key channel of fresh demand, and it is to continue to take international marketing as an example. If the manufacturers want to achieve global sales, whose products belong to the feasible region of quality need to satisfy a higher standard, e.g., ISO[3] 9001 is the QT value. Indeed, many top manufacturers, such as Apple, Dell, HUAWEI, Lenovo, and Samsung, have set up the global production and sales networks, that is because their product quality level is far beyond ISO 9001.

2.3.3. R versus RR

Theorem 3 For the manufacturer, any product distribution in RR absolutely outperforms in R as long as $\Omega < 2$.

Proof. By combining profit functions (9) and (11) under $\Omega \neq 1$, an incremental function in the manufacturer's profit can be computed as follows:

$$\begin{aligned}\Delta\Pi_m\left(q^2\right) &= \Pi_{m|RR} - \Pi_{m|R} \\ &= \frac{1}{8(4\alpha_m - \alpha_r)}\left[3\left(q^2\right)^2 - 2(2\alpha_m + \alpha_r)\left(q^2\right) + 4\alpha_m^2 - 2\alpha_m\alpha_r + \alpha_r^2\right] \text{ if } \alpha_m > \alpha_r\end{aligned},$$

because the discriminant of $\Delta\Pi_{m|RR-R}\left(q^2\right)$ is $\Delta = -8(4\alpha_m - \alpha_r)(\alpha_m - \alpha_r) < 0$, then $\Delta\Pi_{m|RR-R}\left(q^2\right)$ is strictly greater than zero, such that $\Pi_{m|RR} > \Pi_{m|R}\ \forall\ q^2 \in \left(0,\ \frac{\alpha_r}{2}\right]$; meanwhile,

$$\begin{aligned}\Delta\Pi_m\left(q^2\right) &= \Pi_{m|RR} - \Pi_{m|R} \\ &= \frac{1}{8\alpha_m\alpha_r(4\alpha_r - \alpha_m)}\left[\left(4\alpha_r^2 - 2\alpha_m\alpha_r + \alpha_m^2\right)\left(q^2\right)^2 - 2\alpha_m\alpha_r(2\alpha_r + \alpha_m)\left(q^2\right) + 3\alpha_m^2\alpha_r^2\right] \text{ if } \alpha_m < \alpha_r\end{aligned},$$

similarly, the discriminant of $\Delta\Pi_{m|RR-R}\left(q^2\right)$ is $\Delta = -8\alpha_m^2\alpha_r^2\left(4\alpha_r - \alpha_m\right)\left(\alpha_r - \alpha_m\right) < 0$, also $\Delta\Pi_{m|RR-R}\left(q^2\right)$ is strictly greater than zero, such that $\Pi_{m|RR} > \Pi_{m|R}\ \forall\ q^2 \in \left(0,\ \frac{\alpha_m}{2}\right]$.

It is intuitive that a manufacturer may benefit from adding a new retailing channel, that is because a horizontal competition in retailers results in substantial sales. Although a dual-retailer structure may increase bargaining costs of the manufacturer, generous profit from demand expansion can offset the loss of additional costs.

2.3.4. RD versus RR

Theorem 4 If $1 < \Omega$, a relative high quality-level zone (i.e., $\frac{\alpha_m(8\alpha_r+\alpha_m)-\alpha_m\sqrt{(4\alpha_r-\alpha_m)(8\alpha_r+\alpha_m)}}{2(8\alpha_r+\alpha_m)} \le q^2 \le \frac{\alpha_m}{2}$) in RR is superior to in RD for the manufacturer's profit, while a relative low quality-level zone (i.e., $0 < q^2 < \frac{\alpha_m(8\alpha_r+\alpha_m)-\alpha_m\sqrt{(4\alpha_r-\alpha_m)(8\alpha_r+\alpha_m)}}{2(8\alpha_r+\alpha_m)}$) in RR is inferior to in RD.

Proof. By combining profit functions (10) and (11) under $1 < \Omega$, an increment in the manufacturer's profit can be viewed as the function of quality,

$$\begin{aligned}\Delta\Pi_m\left(q^2\right) &= \Pi_{m|RD} - \Pi_{m|RR} \\ &= \frac{\alpha_r - \alpha_m}{4\alpha_m(4\alpha_r - \alpha_m)(8\alpha_r + \alpha_m)}\left[2(8\alpha_r + \alpha_m)\left(q^2\right)^2 - 2\alpha_m(8\alpha_r + \alpha_m)\left(q^2\right) + \alpha_m^2(2\alpha_r + \alpha_m)\right]\end{aligned},$$

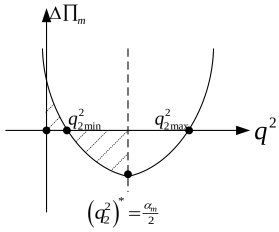
[3] ISO is the abbreviation of International Organization for Standardization.

because the axis of symmetry $(q_2^2)^* = \frac{\alpha_m}{2} > 0$ is the upper boundary of quality value, we need to solve $\Delta\Pi_{m|RD-RR}\left(q^2\right) = 0$ and get its two roots like

$$q_{2\min}^2 = \frac{\alpha_m\left(8\alpha_r + \alpha_m\right) - \alpha_m\sqrt{\left(4\alpha_r - \alpha_m\right)\left(8\alpha_r + \alpha_m\right)}}{2\left(8\alpha_r + \alpha_m\right)} > 0$$

$$q_{2\max}^2 = \frac{\alpha_m\left(8\alpha_r + \alpha_m\right) + \alpha_m\sqrt{\left(4\alpha_r - \alpha_m\right)\left(8\alpha_r + \alpha_m\right)}}{2\left(8\alpha_r + \alpha_m\right)}$$

, furthermore,



we know that $q_{2\min}^2$ is another QT value (QT2) by analyzing (see shaded part in right schematic diagram), and thus, the following conclusion can be obtained:

$$\begin{cases} \Pi_{m|RD} > \Pi_{m|RR} \quad \text{when} \quad q^2 \in \left(0,\ \frac{\alpha_m(8\alpha_r+\alpha_m)-\alpha_m\sqrt{(4\alpha_r-\alpha_m)(8\alpha_r+\alpha_m)}}{2(8\alpha_r+\alpha_m)}\right] \\ \Pi_{m|RD} < \Pi_{m|RR} \quad \text{when} \quad q^2 \in \left[\frac{\alpha_m(8\alpha_r+\alpha_m)-\alpha_m\sqrt{(4\alpha_r-\alpha_m)(8\alpha_r+\alpha_m)}}{2(8\alpha_r+\alpha_m)},\ \frac{\alpha_m}{2}\right] \end{cases}.$$

Theorem 4 uncovers that the manufacturer engages in distribution of products in a dual-channel structure is not always succeed, particularly high quality-level zone, which is needed to match more professional sales agents, such as an independent retailer.

2.3.5. R versus RD

Theorem 5 For the manufacturer, any product distribution in RD absolutely outperforms in R as long as $1 < \Omega$.

Proof. By combining profit functions (9) and (10) under $1 < \Omega$, an incremental function in the manufacturer's profit can be computed as follows:

$$\begin{aligned} \Delta\Pi_m\left(q^2\right) &= \Pi_{m|RD} - \Pi_{m|R} \\ &= \frac{1}{8\alpha_m\alpha_r\left(8\alpha_r + \alpha_m\right)}\left[\left(2\alpha_r - \alpha_m\right)\left(8\alpha_r + \alpha_m\right)\left(q^2\right)^2 - 2\alpha_m\alpha_r\left(8\alpha_r + \alpha_m\right)\left(q^2\right) + \alpha_m^2\alpha_r\left(7\alpha_r + 2\alpha_m\right)\right], \end{aligned}$$

because the discriminant of $\Delta\Pi_{m|RD-R}\left(q^2\right)$ is $\Delta = 8\alpha_m^2\alpha_r\left(\alpha_m - \alpha_r\right)\left(\alpha_m + 3\alpha_r\right)\left(\alpha_m + 8\alpha_r\right) < 0$, then $\Delta\Pi_{m|RD-R}\left(q^2\right)$ is strictly greater than zero, such that $\Pi_{m|RD} > \Pi_{m|R}\ \forall\ q^2 \in \left(0,\ \alpha_r\right]$.

Combining theorems **2** and **5**, when consumers prefer retailing channel (α_r) to direct channel (α_m) to purchase the product at the initial stage of sales, the profit performance of manufacturers in hybrid-channel perfectly exceeds in any type of single channel within all quality-level zones. The comparative advantage of RD is weakened the double marginalization problem due to horizontal competition mechanism. Because competitions in channels urge the retailer to undertake more effective promotional efforts, such as price concessions, joint promotion, etc., to attract more consumers for purchasing. The manufacturer, on the other hand, needs to make some concession on wholesale price for the retailer, but the manufacturer still can gain excess profit to offset the loss of a lower wholesale price.

2.3.6. D versus RR

Theorem 6 For the manufacturer, any product distribution in RR is superior to in D if

$1<\Omega$; in contrast, any product distribution in RR is inferior to in D if $\Omega<1$.

Proof. By combining profit functions (8) and (11) under $\Omega\neq 1$, an increment in the manufacturer's profit can be viewed as the function of quality,

$$\begin{aligned}\Delta\Pi_m\left(q^2\right) &= \Pi_{m|RR}-\Pi_{m|D}\\ &= \frac{\alpha_m-\alpha_r}{4\alpha_m\alpha_r\left(4\alpha_m-\alpha_r\right)}\left[(2\alpha_m-\alpha_r)\left(q^2\right)^2+2\alpha_m\alpha_r\left(q^2\right)-2\alpha_m^2\alpha_r\right] \text{ if } \alpha_m>\alpha_r\end{aligned},$$

because the axis of symmetry is $(q_3^2)^*=-\frac{\alpha_m\alpha_r}{2\alpha_m-\alpha_r}<0$, we need to solve $\Delta\Pi_{m|RR-D}\left(q^2\right)=0$ and get its two roots like

$$q_{3\min}^2=\frac{-\alpha_m\alpha_r-\alpha_m\sqrt{\left(4\alpha_m-\alpha_r\right)\alpha_r}}{2\alpha_m-\alpha_r}<0,\ q_{3\max}^2=\frac{-\alpha_m\alpha_r+\alpha_m\sqrt{\left(4\alpha_m-\alpha_r\right)\alpha_r}}{2\alpha_m-\alpha_r}>\frac{\alpha_r}{2},$$

because $\Delta\Pi_{m|RR-D}\left(q^2\right)<0\ \forall\ q^2\in\left(0,\ \frac{\alpha_r}{2}\right]$, and thus, $\Pi_{m|D}>\Pi_{m|RR}$; meanwhile,

$$\begin{aligned}\Delta\Pi_m\left(q^2\right) &= \Pi_{m|D}-\Pi_{m|RR}\\ &= \frac{\alpha_r-\alpha_m}{4\alpha_m\left(4\alpha_r-\alpha_m\right)}\left[2\left(q^2\right)^2-2\alpha_m\left(q^2\right)-\alpha_m\left(2\alpha_r-\alpha_m\right)\right] \text{ if } \alpha_m<\alpha_r\end{aligned},$$

because the axis of symmetry $(q_4^2)^*=\frac{\alpha_m}{2}>0$ is the upper boundary of quality value, we need to solve $\Delta\Pi_{m|D-RR}\left(q^2\right)=0$ and get its two roots like

$$q_{4\min}^2=\frac{\alpha_m-\sqrt{\left(4\alpha_r-\alpha_m\right)\alpha_m}}{2}<0,\ q_{4\max}^2=\frac{\alpha_m+\sqrt{\left(4\alpha_r-\alpha_m\right)\alpha_m}}{2},$$

because $\Delta\Pi_{m|D-RR}\left(q^2\right)<0\ \forall\ q^2\in\left(0,\ \frac{\alpha_m}{2}\right]$, and thus, $\Pi_{m|D}<\Pi_{m|RR}$.

Obviously, **Theorem 6** differs from theorems **2**, **3** and **5**, which depicts that a dual-retailer structure is not always succeed in distribution of the products. In contrast, the manufacturer directly engages in distribution of products is also a dominant strategy of improving its own performance.

Taking asymmetric preference of purchase channels choice by the consumers for consideration, the following inference can be obtained from theorems **1-6**:

Corollary 1 Combining all the aforementioned comparisons, differential quality-level zone is given by quality intervention, and the optimal channel strategy in each quality-level zone can be selected. When $1<\Omega<2$, the matching strategies of manufacturers are summarized as follows:

- In high quality-level zone, the preference of channel is $RR\succ RD\succ R\succ D$;
- In medium quality-level zone, the preference of channel is unstable;
- In low quality-level zone, the preference of channel is $RD\succ RR\succ D\succ R$;

but the boundary of quality-level zone which changes with Ω value (see Table **4** and Figure **3**). When $\Omega<1$, the hybrid-channel is failure first, and thus, the preference of channel in any product is $D\succ RR\succ R$, which suggests the manufacturer not should concentrate on product itself, but should focus on channel optimization.

Table 4: Quality-level zones under asymmetric preference

$q^2 \rightarrow$	High quality-level	Medium quality-level	Low quality-level
$\Omega<1$	$\left(0,\frac{\alpha_r}{2}\right]$		
$1<\Omega<\frac{3+\sqrt{5}}{4}$	/	$\left(\frac{\alpha_m(8\alpha_r+\alpha_m)-\alpha_m\sqrt{(4\alpha_r-\alpha_m)(8\alpha_r+\alpha_m)}}{2(8\alpha_r+\alpha_m)},\frac{\alpha_m}{2}\right]$ $RR\succ RD\succ D\succ R$	$\left(0,\frac{\alpha_m(8\alpha_r+\alpha_m)-\alpha_m\sqrt{(4\alpha_r-\alpha_m)(8\alpha_r+\alpha_m)}}{2(8\alpha_r+\alpha_m)}\right]$
$\frac{3+\sqrt{5}}{4}<\Omega<\Omega^*$	$\left(\frac{\sqrt{\alpha_m\alpha_r}\left(\sqrt{2\alpha_m}-\sqrt{\alpha_r}\right)}{\sqrt{2\alpha_r}-\sqrt{\alpha_m}},\frac{\alpha_m}{2}\right]$	$\left(\frac{\alpha_m(8\alpha_r+\alpha_m)-\alpha_m\sqrt{(4\alpha_r-\alpha_m)(8\alpha_r+\alpha_m)}}{2(8\alpha_r+\alpha_m)},\frac{\sqrt{\alpha_m\alpha_r}\left(\sqrt{2\alpha_m}-\sqrt{\alpha_r}\right)}{\sqrt{2\alpha_r}-\sqrt{\alpha_m}}\right]$ $RR\succ RD\succ D\succ R$	$\left(0,\frac{\alpha_m(8\alpha_r+\alpha_m)-\alpha_m\sqrt{(4\alpha_r-\alpha_m)(8\alpha_r+\alpha_m)}}{2(8\alpha_r+\alpha_m)}\right]$
$\Omega^*<\Omega<2$	$\left(\frac{\alpha_m(8\alpha_r+\alpha_m)-\alpha_m\sqrt{(4\alpha_r-\alpha_m)(8\alpha_r+\alpha_m)}}{2(8\alpha_r+\alpha_m)},\frac{\alpha_m}{2}\right]$	$\left(\frac{\sqrt{\alpha_m\alpha_r}\left(\sqrt{2\alpha_m}-\sqrt{\alpha_r}\right)}{\sqrt{2\alpha_r}-\sqrt{\alpha_m}},\frac{\alpha_m(8\alpha_r+\alpha_m)-\alpha_m\sqrt{(4\alpha_r-\alpha_m)(8\alpha_r+\alpha_m)}}{2(8\alpha_r+\alpha_m)}\right]$ $RD\succ RR\succ R\succ D$	$\left(0,\frac{\sqrt{\alpha_m\alpha_r}\left(\sqrt{2\alpha_m}-\sqrt{\alpha_r}\right)}{\sqrt{2\alpha_r}-\sqrt{\alpha_m}}\right]$

Proof. When $1<\Omega<2$, assuming $\frac{\sqrt{\alpha_m\alpha_r}\left(\sqrt{2\alpha_m}-\sqrt{\alpha_r}\right)}{\sqrt{2\alpha_r}-\sqrt{\alpha_m}}<\frac{\alpha_m}{2}$, which can be rewritten as $\alpha_m^2\left(4\Omega^2-6\Omega+1\right)>0$, and we know that $\Omega<\frac{3-\sqrt{5}}{4}$ (×) or $\Omega>\frac{3+\sqrt{5}}{4}$ (≈ 1.314). In addition, $\frac{\sqrt{\alpha_m\alpha_r}\left(\sqrt{2\alpha_m}-\sqrt{\alpha_r}\right)}{\sqrt{2\alpha_r}-\sqrt{\alpha_m}}>\frac{\alpha_m}{2}$ when $1<\Omega<\frac{3+\sqrt{5}}{4}$. Because $\Omega\equiv{\alpha_r}/{\alpha_m}$, QT1 and QT2 can be redefined as $QT_1=\frac{\sqrt{\alpha_m\alpha_r}\left(\sqrt{2\alpha_m}-\sqrt{\alpha_r}\right)}{\sqrt{2\alpha_r}-\sqrt{\alpha_m}}=\alpha_m\left(1-\frac{\Omega-1}{\sqrt{2\Omega-1}}\right)$ and $QT_2=\frac{\alpha_m(8\alpha_r+\alpha_m)-\alpha_m\sqrt{(4\alpha_r-\alpha_m)(8\alpha_r+\alpha_m)}}{2(8\alpha_r+\alpha_m)}=\alpha_m\cdot{1}/{2}\cdot\left(1-\sqrt{\frac{4\Omega-1}{8\Omega+1}}\right)$, furthermore, there exists a unique point (Ω^*) between two threshold curves by analyzing (see Figure **3**), and we can conclude as follows:

$$\begin{cases}\frac{\sqrt{\alpha_m\alpha_r}\left(\sqrt{2\alpha_m}-\sqrt{\alpha_r}\right)}{\sqrt{2\alpha_r}-\sqrt{\alpha_m}}>\frac{\alpha_m(8\alpha_r+\alpha_m)-\alpha_m\sqrt{(4\alpha_r-\alpha_m)(8\alpha_r+\alpha_m)}}{2(8\alpha_r+\alpha_m)} & \text{when } 1<\Omega<\Omega^* \\ \frac{\sqrt{\alpha_m\alpha_r}\left(\sqrt{2\alpha_m}-\sqrt{\alpha_r}\right)}{\sqrt{2\alpha_r}-\sqrt{\alpha_m}}<\frac{\alpha_m(8\alpha_r+\alpha_m)-\alpha_m\sqrt{(4\alpha_r-\alpha_m)(8\alpha_r+\alpha_m)}}{2(8\alpha_r+\alpha_m)} & \text{when } \Omega^*<\Omega<2\end{cases}.$$

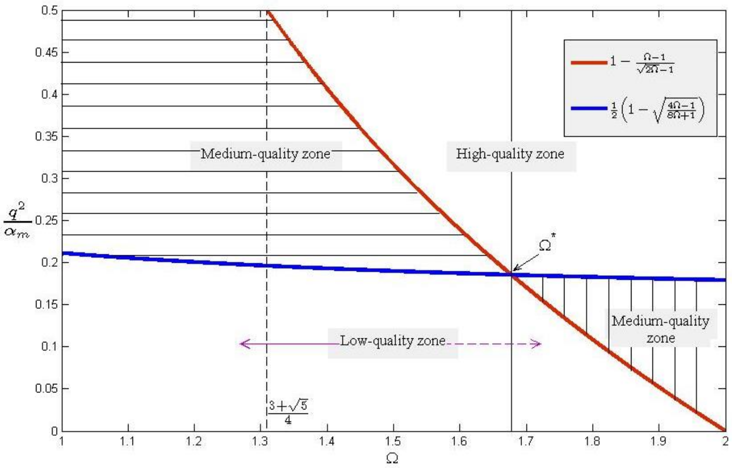


Fig. 3 Branch and bound through QT values ($\Omega^*\approx 1.6775$)

2.4. Strategy Selection of The Retailer – A special case study

In the process of supply chain efficiency management, retailers' behavioral preferences cannot be neglected undoubtedly. When $\Omega<1$, the retailer should give up on cooperation with the manufacturer under information symmetry, because the manufacturer not only owns products but also gains the competitive edge of channel. In contrast, another key aspect investigated in this paper is the effects of the manufacturer's matching strategies on the retailer's cooperation mechanism when

$1<\Omega<2$. Especially, the roles between an existing retailer and a new retailer are symmetric, and this section considers the existing retailer only. Similarly with profit function of the manufacturer, the retailer's profit function is equally connected with product quality, which can be calculated in any channel structure as follows:

$$\Pi_{r|R}=\frac{(\alpha_r-q^2)^2}{16\alpha_r}, \tag{12}$$

$$\Pi_{r|RD}=\frac{(\alpha_r-\alpha_m)\cdot(2\alpha_r+\alpha_m)^2}{(8\alpha_r+\alpha_m)^2}, \tag{13}$$

$$\Pi_{r|RR}=\frac{(\alpha_r-\alpha_m)\cdot(2\alpha_r-q^2)^2}{4(4\alpha_r-\alpha_m)^2}. \tag{14}$$

Combining some horizontal comparisons by the retailer and quality-level zones by the manufacturer, the following inference can be obtained with subject to $\alpha_m<\alpha_r$ and $0<q^2\le\frac{\alpha_m}{2}$.

Corollary 2 For the retailer, it is unwise to cooperate with other independent retailers, such that dual-retailer structure is a bad strategy. Furthermore, the retailer chooses either exclusive retailing channel or hybrid-channel structure, mainly depending on differential acceptance region (see Figure **4**).

Proof. By combining profit functions (12) and (14) under $1<\Omega$, an incremental function in the retailer's profit can be computed as follows:

$$\begin{aligned}\Delta\Pi_r\left(q^2\right)&=\Pi_{r|R}-\Pi_{r|RR}\\&=\frac{1}{16\alpha_r\left(4\alpha_r-\alpha_m\right)^2}\left[\left(12\alpha_r^2-4\alpha_r\alpha_m+\alpha_m^2\right)\cdot\left(q^2\right)^2-2\alpha_r\left(8\alpha_r^2+\alpha_m^2\right)\cdot\left(q^2\right)+\alpha_r^2\alpha_m\left(8\alpha_r+\alpha_m\right)\right],\end{aligned}$$

because the minimum root of $\Delta\Pi_{r|R-RR}\left(q^2\right)=0$ is $\frac{\alpha_r\left(8\alpha_r^2+\alpha_m^2\right)-2\alpha_r\left(4\alpha_r-\alpha_m\right)\sqrt{\alpha_r\left(\alpha_r-\alpha_m\right)}}{12\alpha_r^2-4\alpha_r\alpha_m+\alpha_m^2}$ ($\equiv\alpha_m\cdot\frac{\Omega+8\Omega^3-2\Omega(4\Omega-1)\sqrt{\Omega(\Omega-1)}}{12\Omega^2-4\Omega+1}$), and which is greater than $\frac{\alpha_m}{2}$, such that $\Delta\Pi_{r|R-RR}\left(q^2\right)>0\ \forall\ q^2\in\left(0,\ \frac{\alpha_m}{2}\right]$, and thus $\Pi_{m|R}>\Pi_{m|RR}$. By combining profit functions (13) and (14) under $1<\Omega$, on the other hand, an incremental function in the retailer's profit is

$$\begin{aligned}\Delta\Pi_r\left(q^2\right)&=\Pi_{r|RR}-\Pi_{r|RD}\\&=\frac{\left(\alpha_r-\alpha_m\right)\cdot\left(2\alpha_r-q^2\right)^2}{4\left(4\alpha_r-\alpha_m\right)^2}-\frac{\left(\alpha_r-\alpha_m\right)\cdot\left(2\alpha_r+\alpha_m\right)^2}{\left(8\alpha_r+\alpha_m\right)^2},\end{aligned}$$

because the axis of symmetry is $2\alpha_r$ and the minimum root of $\Delta\Pi_{r|RR-RD}\left(q^2\right)=0$ is $-\frac{2\alpha_m\left(\alpha_r-\alpha_m\right)}{8\alpha_r+\alpha_m}$, and thus $\Delta\Pi_{r|RR-RD}\left(q^2\right)<0\ \forall\ q^2\in\left(0,\ \frac{\alpha_m}{2}\right]$, such that $\Pi_{m|RR}<\Pi_{m|RD}$.

Lastly, by combining profit functions (12) and (13) under $1<\Omega$, an incremental function in the retailer's profit can be computed as follows:

$$\begin{aligned}\Delta\Pi_r\left(q^2\right)&=\Pi_{r|R}-\Pi_{r|RD}\\&=\frac{\left(\alpha_r-q^2\right)^2}{16\alpha_r}-\frac{\left(\alpha_r-\alpha_m\right)\cdot\left(2\alpha_r+\alpha_m\right)^2}{\left(8\alpha_r+\alpha_m\right)^2},\end{aligned}$$

because the axis of symmetry is α_r and the minimum root of $\Delta\Pi_{r|R-RD}\left(q^2\right)=0$ is $\alpha_r-\frac{4\left(2\alpha_r+\alpha_m\right)\sqrt{\alpha_r\left(\alpha_r-\alpha_m\right)}}{8\alpha_r+\alpha_m}$ ($\equiv\alpha_m\left(\Omega-\frac{4(2\Omega+1)\sqrt{\Omega(\Omega-1)}}{8\Omega+1}\right)$)>0, we further need to determine the size of minimum root and upper boundary of quality value, and we found that there exists a unique point (Ω^{**}) between two threshold curves by analyzing (see Figure **4**).

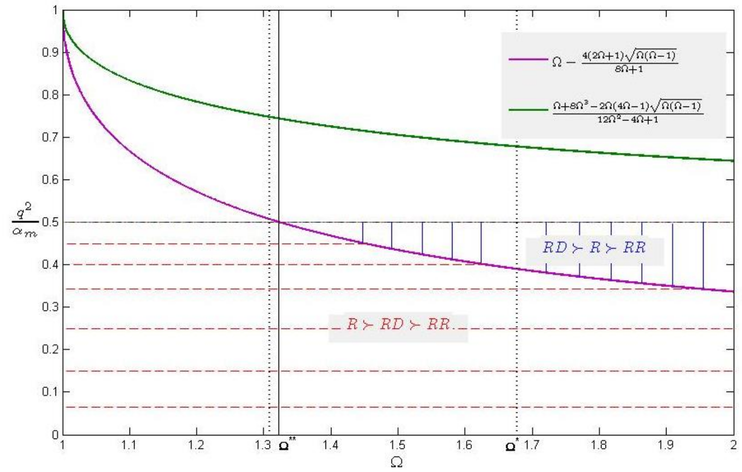


Fig. 4 Acceptance regions and channel strategy of the retailer ($\Omega^{**}\approx 1.323$)

Combining corollaries **1** and **2**, the supply chain system cannot achieve global Pareto improvement without any additional coordination mechanism between the manufacturer and the retailer. However, the key point is the discussion of strategy decision-making of the manufacturer rather than the whole supply chain for this research, and thus, coordination is not considered in the following text.

Next, to further comprehend our matching model and the obtained results, numerical simulations and extended discussions were performed under different decision-making environments.

3. Numerical Simulations and Theoretical Discussions

To determine the effects of quality intervention, quality threshold and quality-level zone on product variety and channel decision-making of the manufacturer, we tested the robustness of theoretical results by using numerical algorithms.

Theoretically, the hybrid-channel structure is failure when $\alpha_m > \alpha_r$, which is caused by complete information symmetry between the manufacturer and the retailer. But in practice, the manufacturer wants to pure bigger profit targets through dual channels that prompts it to take trading risks, provide shoddy products ($q^2 < 0$) in the retailing channel under incomplete information symmetry. Figure **5** depicts the performance of hybrid-channel RD compared with the optimal channel strategy D irrespective of any quality-level when α_m=450 and α_r=360. In fact, the predominance of RD is not obvious, because the profits gap in D and RD becomes less and less effective. However, compared with potential risks of supply chain, which is made by shoddy products of the manufacturer, the hybrid-channel structure leads to a slight increase in the manufacturer's profit can be completely neglected. For example, Lao-tan pickled cabbage instant noodles as one product of Master Kong was exposed by China Central Television that there is quality problem in using pickled cabbage in World Consumer Right Day (3·15) in 2022. The pickled cabbage as an important part of Lao-tan instant noodles, whose manufacturer, such as CHAQICAIYE, was not only unable to stay in business, but also exposed the Master Kong to criticism. Unfortunately, this event has spread to other FMCG (i.e., the Fast-Moving Consumer Goods) enterprises, including but not limited to Kentucky Fried Chicken, McDonald's, and Uni-President. In the long run, a rational manufacturer should choose to give up the hybrid-channel structure.

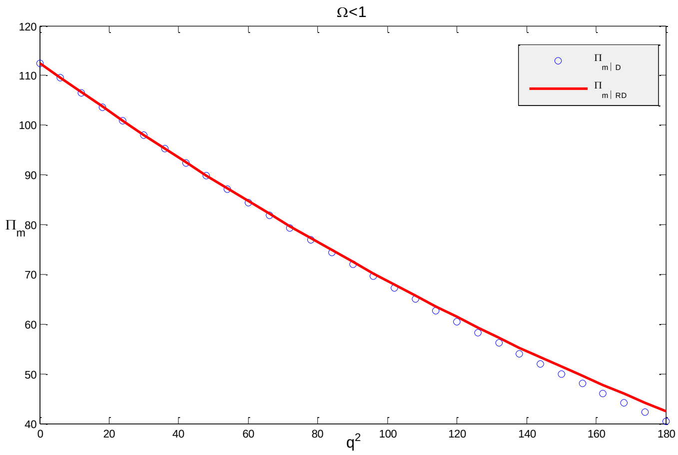


Fig. 5 The performance of hybrid-channel under information asymmetry between the manufacturer and the retailer

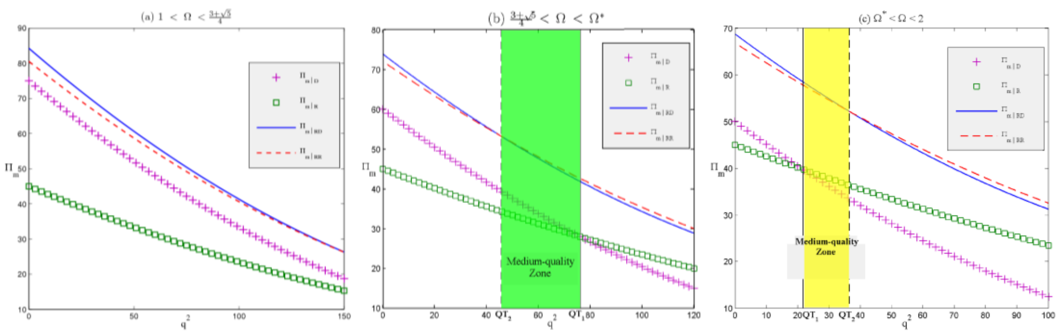


Fig. 6 Combinatorial decision-making between product variety and channel strategy under $\alpha_m < \alpha_r$

Figure **6** depicts the numerical results for the manufacturer's channel preference within any quality-level zone (e.g., product variety) when $\alpha_m < \alpha_r$, and Figure **6a** is in agreement with **Corollary 1** if α_m=300 and α_r=360; Figure **6b** is in agreement with **Corollary 1** if α_m=240 and α_r=360; Figure **6c** is in agreement with **Corollary 1** if

α_m=200 and α_r=360. All of which suggest that in any given quality-level zone, the manufacturer's maximum profit structure can be selected, and this structure enables the manufacturer to try to improve the supply chain system. As depicted in Figure **6**, on the other hand, there exist different quality-level zones, in other words, the manufacturer can implement product variety ($q_H - q_L \neq 0$), especially in figures **b** and **c**. In addition, we found that the influence of the area of medium-quality zone on the manufacturer's product variety, it is obvious that the bigger the area is, the more significant the product variety is. For example, because the green area in Figure **6b** is greater than the yellow area in Figure **6c**, then the manufacturer will be much better implemented product variety under the condition of $\frac{3+\sqrt{5}}{4} < \Omega < \Omega^*$. However, Figure **6a** reveals that the area of medium-quality zone is getting smaller and smaller, and the phenomenon of product variety is getting weaker and weaker ($q_M - q_L \to 0$), by which makes the products become more homogeneous. When Ω is given, the manufacturer can optimize its own product strategy to achieve benefits, such that $[\frac{3+\sqrt{5}}{4}, \Omega^*) \succ [\Omega^*, 2) \succ (1, \frac{3+\sqrt{5}}{4}) \succ (0, 1)$.

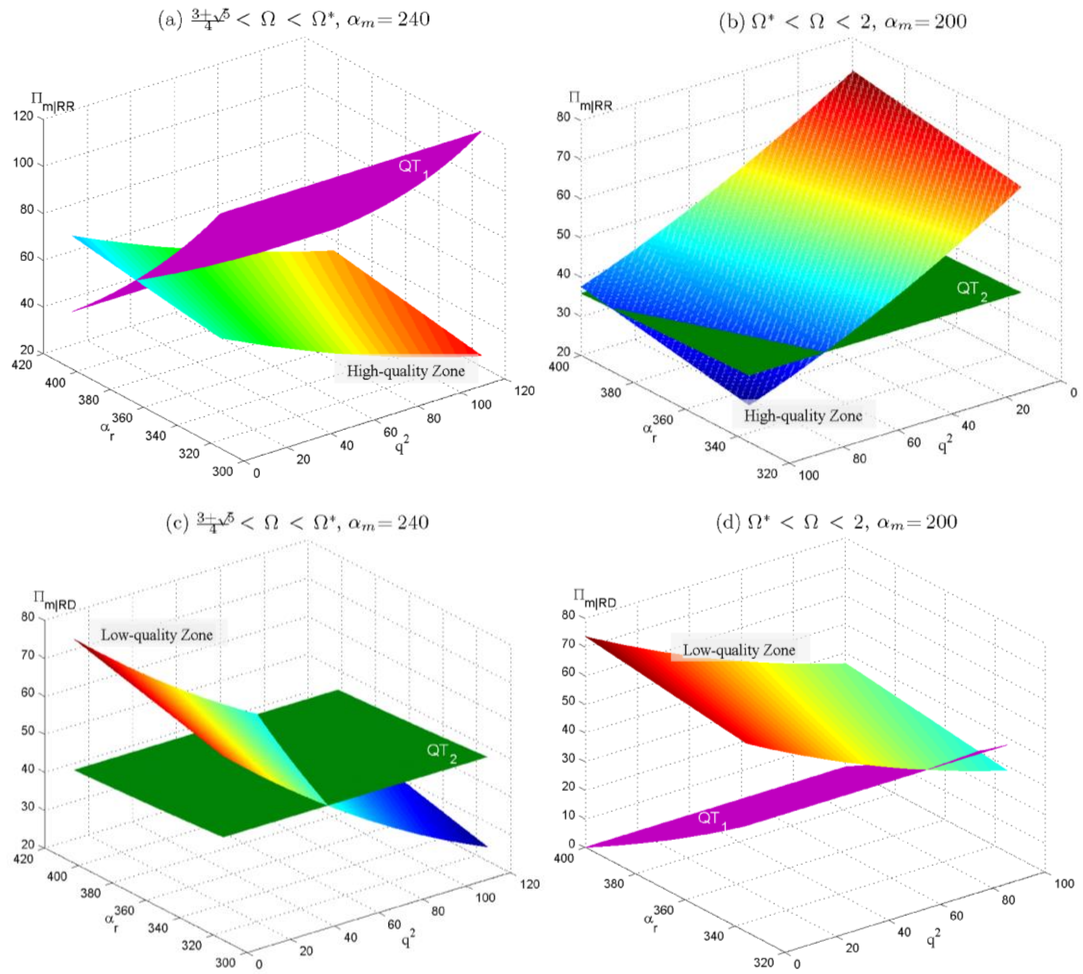


Fig. 7 Sensitivity analysis for optimal channel selection of the manufacturer

Sensitivity analysis is conducted to determine the effects of a retailing channel power and differential quality-level zone on the manufacturer's profit optimization. When α_m is given, assuming q^2 is fixed in the high-quality zone (figures **7a** and **7b**), as α_r increases, the manufacturer's maximum profit asymptotically increases. Meanwhile, when α_m is given, assuming q^2 is fixed in the low-quality zone (figures **7c** and **7d**), as α_r increases, the manufacturer's maximum profit also increases. In conclusion, the manufacturer wants to expand its own maximum profit under the current optimal structure, this motivation enables the manufacturer to attempt to cooperate with the retailer who owns more channel power in future.

4. Conclusions

In this paper, we firstly used asymmetric preference of purchase channels choice by the consumers to carve up a market (e.g., market segmentation), and introduced quality intervention to control quality threshold and quality-level zone, further analyzed how intervention impacts on product variety and channel optimization of the manufacturer.

When direct channel possesses comparative advantage compared with retailing channel, the hybrid-channel structure is failure results from negative demand of the retailer. Under incomplete information symmetry between the manufacturer and the retailer, some manufacturers strongly motivated by profit and competition are willing to still prefer the hybrid-channel structure, which resulting in the existence of shoddy products or *"double standard"* of quality. Theoretically and practically, however, the hybrid-channel structure should be completely neglected, the reason is that potential risks of supply chain absolutely exceed a slight increase in short-term profit of the manufacturer, in short, it must be the loss outweighs the gain. Indeed, we have established that the manufacturer provides acceptable products only through a unified quality standard replaces shoddy products or *"double standard"* of quality, who can benefit from the direct channel. Most importantly, channel strategy should have priority over product strategy.

When retailing channel possesses comparative advantage compared with direct channel, on the other hand, product line can be divided into differential quality-level zone by defining quality threshold, and the preferences of manufacturers and retailers in each quality-level zone within the structures can be ranked, but the supply chain system is very fragile without any additional coordination mechanism. Although quality boundaries of quality-level zone change with channel power (i.e., Ω value), there exist stable channel preferences between high-quality and low-quality zones, while there exists unstable channel preference in medium-quality zone. Whether the preference is stable or not, dual-channel structures dominate single channels. In addition, the area of medium-quality zone directly impacts on the efficiency of product variety, which is also connected with channel power. In conclusion, the manufacturer should lay equal stress on product and channel strategies, and the channel demand further matches with product supply.

In this era of digital business, a crucial decision mainly depends on how much information you have, such as information about a corporation's own strength, its rival's reactions, and the market situation (Bag et al. 2021; Fu *et al.*, 2022; Corsaro and D' Amico, 2022; Fready et al. 2022; Rahman et al. 2023). In this paper, we have considered two types of information, such as asymmetric preference of purchase channels choice by the consumers and information symmetry between the manufacturer and the retailer, by which greatly affect the analytical process of B2B Manufacturer-Stackelberg framework, and the final payoffs of our model can be summarized in Table **5**. However, the limitation of this paper is amplified by the influence of quality on production cost, which encourages us to revise it in future research (Shrivastava, 2023).

Table 5: The final payoffs under two types of information

		The manufacturer and the retailer	
		complete information symmetry	incomplete information symmetry
Asymmetric preference of purchase channels choice by the consumers	direct channel is more powerful	the hybrid-channel is failure	shoddy products or *"double standard"*
	retailing channel is more powerful	the supply chain system cannot achieve global Pareto improvement without any additional coordination mechanism	

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