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Hybrid marketing channel strategies of a manufacturer in a supply chain: game theoretical and numerical approaches

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Abstract
This paper analyzes how the market power in a supply chain affects a manufacturer's hybrid marketing channel strategies, considering market transaction costs and the ratio of market size of the online market and the offline market. Also, this paper investigates a price-matching strategy when a manufacturer adds an online channel. This paper shows a number of interesting results: generally, when a manufacturer acts as a Stackelberg follower, the manufacturer chooses a hybrid marketing channel strategy as online costs become very much smaller and the size of the online market is much larger. However, when a manufacturer acts as a Stackelberg leader, the manufacturer has more chances to use a hybrid marketing channel strategy even when the online costs are relatively higher. In addition, a manufacturer may use a price-matching strategy by lowering its prices with the aim to eventually drive the retailer out of the market if the manufacturer perceives that a retailer has more advantages in the offline market and the size of offline market is larger.

Keywords Channel management · Channel conflict · Game theory · Multichannel · Pricing strategy · Supply chain

1 Introduction

The Internet has led many manufacturers (and conventional retailers) to add direct online channels to their existing retail networks [9, 15, 23]. However, other manufacturers use the Internet only as a medium to provide information about their products without selling via their websites. These examples show that different manufacturers have differing channel strategies.

Whether manufacturers have the same strategies over time will be dependent upon the evolution of Internet and communication technologies. We observe that offline businesses are being negatively affected in many different industries as online businesses grow. For example, retail discount stores, such as Macy, JC Penny, Target, and Sears have closed their offline stores and are planning to close stores due to competition from various online retailers, such as Amazon. Even the mighty Walmart or Costco have felt the pressure and have started to strengthen their online strategies. The demise or store closing of offline discount retailers is mainly due to the undercutting of prices by online retailers and the retailers' services are less valuable to the customer. Their main competitive strategies against online retailers include a price-matching strategy that matches the lowest price of major online retailers, as well as their offline competitors. Even most airline companies, such as American, Delta, and United have set up their online sites, and they are selling tickets to customers directly and reducing or eliminating commissions to bricks-and-mortar travel agencies. Furthermore, airline companies, such as British Airways, Emirates, Virgin Australia, Jetstar offer price match flights (https://www.finder.com.au/price-match-flights). British Airways provides a best price guarantee policy (https://www.britishairways.com) to utilize or maintain their market power (https://www.britishairways.com). In the past, airline tickets were mostly sold in the bricks-and-mortar travel agencies. However, these days, most small travel agencies have been forced out due to competition from the powerful online agencies, such as Expedia and Priceline.com. This phenomenon indicates that the difference between offline costs and online costs are not big enough to justify the reliance on the retailers from the customer's perspective. So, manufacturers face

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more complicated pricing strategies when they deal with powerful retailers, such as Expedia or Priceline, because the outcome will not be the same as when they deal with bricks-and-mortar travel agencies. In particular, previous studies on the price-matching strategies were mainly based on the cases where a manufacturer has more power and plays as a price setter. In this regard, this paper investigates how the market power between manufacturers and retailers affects a manufacturer's marketing channel strategies and pricing strategies considering market transaction costs and the ratio of market size of the online market and the offline market. Also, this paper examines how a price-matching strategy is related to hybrid channel strategies with its managerial implications.

The remainder of this paper is organized as follows. Section 2 reviews previous studies. Section 3 presents and analyses hybrid marketing channel models according to the market power in a supply chain and a price-matching strategy model. Section 4 discusses the results of the study and strategic implications. In Sect. 5, conclusions and future research are discussed.

2 Literature review

There has been increasing interest in a multi-channel retailing strategy as the Internet has led manufacturers (or other firms) to sell their products using a new marketing channel. So far, a hybrid marketing channel has been investigated in many previous studies (e.g., [1, 4, 6, 10, 17, 18, 20, 21]). These studies on multi-channel retailing have considered some factors, such as differences in cost structures [3, 12, 13, 24], service levels [6, 16], customer heterogeneity [9], information density [25], channel coordination [2, 4, 11, 19] and channel conflict [3], market power [14, 26] and others.

The first stream of research on a multi-channel strategy is about the different cost structures involved in offline and online channels. Cai et al. [3] studied the impacts of different price discount contracts distribution strategies focusing on different cost structures and found that a manufacturer can use both offline and online channels when online channel costs were not very high compared to offline costs. Wang et al. [24] explored the channel selection and pricing strategy in a supply chain and found that multi-channel selling is the best choice for the retailer only when the cost-gap is narrow enough.

The second stream of research on a multi-channel strategy is about customer-related issues, such as service level, customer heterogeneity, and information density. Lu et al. [16] highlighted the importance of services from manufacturers in the interactions between two competing manufacturers and their common retailer when end customers were sensitive to both retail price and manufacturer service using a game-theoretic framework. They found that customers received higher service levels when every channel member possessed equal bargaining power and when one manufacturer had some economic advantages in providing services. Chen et al. [6] studied a dual-channel model where a retailer chose its service level and a manufacturer set the delivery time and found that a manufacturer used both channels when the direct channel cost was high and the retailer inconvenience cost was low. On the other hand, the manufacturer used the direct channel only when the direct channel cost was low. Chun et al. [9] analysed the optimal channel strategies of a manufacturer under customer heterogeneity and retail services. They found that a manufacturer chose a dual-channel strategy using both offline and online channels when the relative customer heterogeneity was moderate and the proportion of the service sensitive group was relatively small. Wu et al. [25] examined how information technology affected a monopoly manufacturer's distribution problem in an environment where product information was important for customers to identify their ideal product and found that a manufacturer was less likely to sell through both channels when the proportion of customers who have access to the electronic channel is very high.

The third stream of research is about channel conflict and market power. Raju and Zhang [19] investigated the coordination strategies of a manufacturer and found that pricing strategies, such as quantity discounts or a menu of two-part tariffs were effective in reducing channel conflicts and enhancing channel coordination. Cattani et al. [4] studied the coordination of pricing on the Internet and traditional channels and found that a price-matching strategy (the direct channel and the retail channel are priced the same) was appropriate as long as the retail channel was significantly more convenient than the Internet channel. Cai et al. [3] evaluated the impact of price discount contracts when a manufacturer discounted the wholesale price to a certain portion of the retail price, and found that a price-matching strategy can reduce the channel conflict by inducing more profit for the retailer. Huang et al. [11] investigated the strategic interactions between the retailer's information sharing and supplier's encroachment decisions and showed that retailer's information sharing could be an effective way for deterring supplier encroachment. Zhang et al. [26] investigated a hybrid dual channel setting using game theoretical models, such as the manufacturer Stackelberg, the retailer Stackelberg, and the vertical Nash model and found that channel price orders from high to low were retailer Stackelberg, vertical Nash, and manufacturer Stackelberg and service level orders from high to low were vertical Nash, manufacturer Stackleberg, and retail Stackelberg. Kim and Chun [14] investigated a manufacturer's retailing channel strategy considering the relative market power between a manufacturer and a retailer in the supply chain and found that a manufacturer may use a multi-channel strategy if customers are very heterogeneous with respect to their receptiveness to online shopping. However, they did not analyse how the market power could affect optimal channel strategies.

Many previous studies in channel selection have dealt with market transaction costs and customer heterogeneity, respectively. But, they have rarely considered the market power in a supply chain although it causes channel conflict for a channel selection problem. Our paper differs from the above studies and has the following threefold contributions. First, we investigate how the market power in a supply chain affects a manufacturer's marketing channel strategies. Therefore, we deal with the vertical Nash equilibrium as well as the sequential equilibrium of Stackelberg cases when a retailer or a manufacturer has power. Secondly, we analyse and discuss the strategic implications on the price-matching strategy, which has been rarely studied as a manufacturer's predatory pricing strategy. Thirdly, we derive and compare equilibrium prices analytically and numerically with respect to the profits using several scenarios.

3 The model

We assume that a linear city of length 1 and a representative customer s is uniformly distributed along the linear city, thus $s \in [0, 1]$. We assume the location of a retailer is at 0. Thus, a customer located at 0 has the maximum valuation of the goods, V, and other preferences are decreasingly differentiated according to s. Each customer consumes one or zero units of goods. Thus, given the firm's unit price of the product (p), a customer of type $s \in [0, 1]$ will obtain the following surplus in consuming one unit of the product:

$$U_s = V(s) - p.$$

So, a customer who is located at 0 will obtain the following surplus in consuming one unit of the product:

$$U_0 = V(0) - p.$$

We assume that there are two types of customer segments in the market. A fraction of customers at each location point, m, do not have access to the Internet, while others, $1 - m$, have access to the Internet [8]. Customers in the first segment, m, are loyal to the retail store and do not buy products online. They pay the transportation cost, ts, where t is the transportation cost per unit of length. Customers with access to the Internet, $1 - m$, choose to buy products from the retail store or online store. If a customer buys the goods from the online store, the customer incurs cost, a, which may be a search cost and other costs related to quality uncertainty, security risk, and delivery cost [8]. Then, the utility of a customer with Internet access located at s is

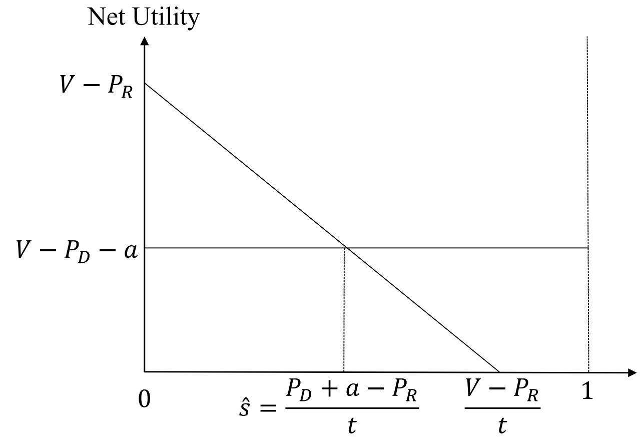

Fig. 1 The choice of customers with Internet access

$$U_s = \begin{cases} V - p_R - ts & \text{if a customer buys from the offline store} \\ V - p_D - a & \text{if a customer buys from the online store} \\ 0 & \text{if a customer does not buy,} \end{cases}$$

where p_R and p_D are the prices charged by the offline and online stores.

Figure 1 depicts a typical equilibrium in the online market, where the net utilities of representative customers are drawn.Letting $\hat{s} = \frac{(p_D + a - p_R)}{t}$, customers with $s < \hat{s}$ prefer the offline store, while customers with $s > \hat{s}$ prefer the online store. Then, the demand functions are given by:

$$D_R = \frac{(1-m)(p_D + a - p_R)}{t} + \frac{m(V - p_R)}{t}$$

$$D_D = (1-m)\left(1 - \frac{(p_D + a - p_R)}{t}\right).$$

3.1 Bricks-and-mortar model (basic model)

In this section, we analyze a bricks-and-mortar model where a manufacturer uses an existing offline retail channel only. We denote this case by the subscript, B. When a manufacturer acts as a Stackelberg leader, the manufacturer charges the retailer a wholesale price w^B per unit.

The retailer then sells the product at a retail price p_R^B. Anticipating the retailer's independent decisions on the retail price, the manufacturer maximizes its own profits:

$$\Pi_M^B = (w - c)\left(\frac{V - p_R}{t}\right)$$

by charging the following wholesale price:

$$w^B = \frac{V + c}{2}$$

Given the wholesale price, a retailer maximizes its profits:

$$\Pi_R^B = (p_R - w)\left(\frac{V - p_R}{t}\right)$$

by charging the following retail price:

$$p_R^B = \frac{1}{2}V + \frac{1}{2}w.$$

Therefore, the manufacturer and retailer obtain the following prices:

$$w^B = \frac{1}{2}V + \frac{1}{2}c, \quad p_R^B = \frac{3}{4}V + \frac{1}{4}c.$$

Also, the profits of the manufacturer and retailer are given by

$$\Pi_M^B = \frac{(V - c)^2}{8t}, \quad \Pi_R^B = \frac{(V - c)^2}{16t}.$$

3.2 Multi-channel models

3.2.1 Manufacturer Stackelberg leader model

We analyse a manufacturer Stackelberg leader model [22] where a manufacturer sells its products through both online and offline channels at the same time. Thus, a manufacturer takes a retailer's reaction function into consideration in order to find a wholesale price, w^{MS}, and a direct online price, p_D^{MS}, maximizing its profits. Then, in the second period, the retailer finds an optimal retail price, p_R^{MS}, by using the manufacturer's wholesale and direct online prices. From the first order conditions of reaction functions, we obtain equilibrium prices as follows:[1]

$$w^{MS^*} = \frac{t}{2m} + \frac{V + c - t}{2}, \quad p_D^{MS^*} = \frac{t}{2m} + \frac{V + c - a}{2},$$
$$p_R^{MS^*} = \frac{t}{2m} + \frac{V + c - t}{2} + \frac{a}{4} + \frac{V - c - a}{4}m.$$

3.2.2 Retailer Stackelberg leader model

We analyse a case where a retailer acts as a Stackelberg leader and a manufacturer acts as a Stackelberg follower. Thus, a retailer, as a market leader, takes a manufacturer's reaction function into account for its own retail price decision. So, in the first period, the retailer maximizes its profits considering the manufacturer's reaction function. Then, in the second period, the manufacturer decides its wholesale and online prices, anticipating the retailer's profit margin, $k = p_R^{RS} - w$. Then, we obtain optimal prices as follows:[2]

$$w^{RS*} = \frac{\left(2t + 2Vm + 2cm - am - 2mt - Vm^2 + am^2 + cm^2\right)}{4m},$$
$$p_D^{RS*} = \frac{(t + Vm - am + cm)}{2m}$$
$$p_R^{RS*} = \frac{\left(2t + 2Vm + 2cm + am - 2mt + Vm^2 - am^2 - cm^2\right)}{4m}.$$

3.2.3 The vertical Nash model

Choi [7] used the term "vertical Nash" in order to distinguish this game from the Nash game played between different channels. A manufacturer chooses its wholesale price and a direct online price conditional on the retailer's margin; $k = p_R^N - w$. Also, a retailer chooses its retail price to maximize its profits anticipating the manufacturer's wholesale price and direct online price. Then, we obtain optimal prices as follows:[3]

$$w^{N*} = \frac{3Vm - Vm^2 - am + 3cm + 3t - 3mt + am^2 + cm^2}{6m},$$
$$p_D^{N*} = \frac{Vm + t - am + cm}{2m},$$
$$p_R^{N*} = \frac{3Vm + Vm^2 + am + 3cm + 3t - 3mt - am^2 - cm^2}{6m}.$$

3.3 The price-matching model

We analyse the price-matching model where a manufacturer acts as a Stackelberg leader and sets the same online price as the existing offline retailer's price, thus, $p_R^{PM} = p_D^{PM}$, where *PM* denotes the price-matching model. Thus, the profits of the retailer are given by:

$$\Pi_R^{PM} = \left(p_R^{PM} - w^{PM}\right)\left(m\frac{V - p_R^{PM}}{t} + (1 - m)\frac{a}{t}\right).$$

Then, in the second period, the retailer finds an optimal retail price to maximize its profits as follows:

$$p_R^{PM} = \frac{\left(Vm - cm + w^{PM}m + a\right)}{2m}.$$

In the first period, the manufacturer chooses an optimal wholesale price to maximize its profits anticipating an

[1] The proofs are in "Appendix 1".

[2] The proofs are in "Appendix 2".

[3] The proofs are in "Appendix 3".

Table 1 Equilibrium prices for hybrid marketing channel models

Models	Equilibrium prices
Basic model (Bricks-and-mortar model)	$w^B = \frac{V+c}{2}, \quad p_R^B = \frac{3V+c}{4}$
Manufacturer leader model	$w^{MS*} = \frac{t}{2m} + \frac{V+c-t}{2}, \quad p_D^{MS*} = \frac{t}{2m} + \frac{V+c-a}{2}$ $p_R^{MS*} = \frac{t}{2m} + \frac{(V+c-t)}{2} + \frac{m(V-c-a)+a}{4}$
Retailer leader model	$w^{RS*} = \frac{t}{2m} + \frac{V+c-t}{2} - \frac{mV+(1-m)a-mc}{4}$ $p_D^{RS*} = \frac{t}{2m} + \frac{V+c-a}{2}, \quad p_R^{RS*} = \frac{t}{2m} + \frac{(V+c-t)}{2} + \frac{m(V-c-a)+a}{4}$
Vertical Nash model	$w^{N*} = \frac{t}{2m} + \frac{V+c-t}{2} - \frac{mV+(1-m)a-mc}{6}$ $p_D^{N*} = \frac{t}{2m} + \frac{V+c-a}{2}, \quad p_R^{N*} = \frac{t}{2m} + \frac{(V+c-t)}{2} + \frac{m(V-c-a)+a}{6}$
Price-matching model	$w^{PM*} = \frac{t}{2m} + \frac{V+c-a}{2}$ $p_R^{PM} = p_D^{PM} = \frac{1}{4m}(2a+t) + \frac{1}{4}(3V-2a+c-t)$ $= p_D^{MS*} + \frac{2a-t}{4m} + \frac{V-t-c}{4}$

offline retail price. Then, the wholesale and retail prices are obtained as follows:

$$w^{PM^*} = \frac{1}{2m}(t + Vm + cm - tm)$$

$$p_D^{PM^*} = p_R^{PM^*} = \frac{1}{4m}(2a + t + 3Vm - 2am + cm - tm).$$

4 Optimal pricing and marketing channel strategies

4.1 Pricing strategies

Table 1 shows the equilibrium prices for the basic model (bricks-and-mortar model), a manufacturer Stackelberg leader model, a vertical Nash model, a retailer Stackelberg leader model and a price-matching strategy model.

As shown in Table 1, online prices are the same for a manufacturer leader model, a vertical Nash model and a retailer leader model. Also, the online prices increase as the size of the offline market (m) decreases and the inefficiency of the online market for the customer (a) decreases.

In a manufacturer leader model, a manufacturer chooses wholesale and online prices considering the inefficiency of the offline market for the customer (t) and the inefficiency of the online market for the customer (a). If $t = a$, then these two prices are the same. If it is less convenient for customers to buy goods online rather than offline ($t > a$), a direct online price is higher than a wholesale price. However, an offline retail price is higher than a direct online price if t is lower than a (or online shopping is less convenient than offline shopping).

In the perspective of market power in a supply chain, a manufacturer in a vertical Nash model has less market power than a manufacturer Stackelberg leader model, while a retailer in a vertical Nash model has more market power than a manufacturer Stackelberg leader model. The optimal online price in the vertical Nash model is the same as that in the manufacturer leader model, while the optimal wholesale and retail prices in the vertical Nash model are lower than those in the manufacturer Stackelberg leader model.

The optimal online price in a retailer Stackelberg leader model is the same as other models, such as the manufacturer leader model, the vertical Nash model, and the manufacturer follower model. The wholesale price is lower than that of the vertical Nash model and the retail price in the retailer Stackelberg leader model is the same as that in the manufacturer Stackelberg leader model. Thus, the retailer's profit margin is the largest when it is compared to other models.

In the price-matching strategy model, a wholesale price is the same as that in the manufacturer Stackelberg leader model. The offline price and direct online price are the same and these prices are higher than the online price in the manufacturer leader model. Proposition 1 shows pricing strategies according to the market power in a supply chain.

Proposition 1

(i) $p_D^{MS} = p_D^{VN} = p_D^{RS}$
(ii) $p_R^{MS} = p_R^{RS} \geq p_R^{VN}$
(iii) $w^{MS} \geq w^{VN} \geq w^{RS}$

(iv) $(p_R^{RS} - w^{RS}) : (p_R^{VN} - w^{VN}) : (p_R^{MS} - w^{MS}) = 4 : 3 : 2$

Proof (i)–(iii) Omitted because of simple calculation. (iv) $p_R^{RS} - w^{RS} = \frac{(V-a-c)m+a}{2}$, $p_R^{VN} - w^{VN} = \frac{(V-a-c)m+a}{3}$, $p_R^{MS} - w^{MS} = \frac{(V-a-c)m+a}{4}$.

Proposition 1 compares optimal wholesale, direct online and offline retail prices for each model. The Proposition 1-(i) shows that online prices do not vary depending on the market power in a supply chain but stay the same. The Proposition 1-(ii) shows that offline retail prices are the same in the manufacturer leader and retailer leader model and they are higher than those in the vertical Nash model. The Proposition 1-(iii) shows that a manufacturer sets a wholesale price depending on the market power in a supply chain. The manufacturer sets a wholesale price, which is the highest in the manufacturer leader model and the lowest in the retailer leader model. Proposition 1-(ii) and (iii) imply that, if a manufacturer acts as a Stackelberg follower, a retailer's profit margin is greater than if it acts as a Stackelberg leader because it sets a wholesale price lower when it acts as a Stackelberg follower. Proposition 1-(iv) shows how profit margins differ according to the market power in the supply chain. So, a retailer's profit margin is the greatest in the retailer Stackelberg leader model and the smallest in the manufacturer Stackelberg leader model. The ratio of the retail profit margin is 4:3:2 according to the market power in the supply chain. This is consistent with a general belief that, if a firm has more market power, its profit margin also increases. So, retail margins are the highest when a retailer acts as a Stackelberg leader and the lowest when a manufacturer acts as a Stackelberg leader. Proposition 2 shows how retail prices are affected by several factors, such as the size of the market and the transaction costs of the two markets.

Proposition 2

(i) $\frac{dp_D^{MS}}{dm} < 0, \quad \frac{dp_D^{VN}}{dm} < 0, \quad \frac{dp_D^{RS}}{dm} < 0$

(ii) $\frac{d(p_R - p_D)}{dm} > 0, \quad \frac{d(p_R - p_D)}{da} > 0, \quad \frac{d(p_R - p_D)}{dt} < 0$

Proof Omitted because of simple calculation.

Proposition 2 explains how some parameters such as m, a, t are related to optimal prices. The Proposition 2-(i) shows that an online price decreases as the size of the offline market (m) increases. The Proposition 2-(ii) shows that an offline price can be higher than an online price when the size of the offline market (m) and the inefficiency of the online market (a) increase and the inefficiency of the offline market (t) decrease.

For the further analysis of the differences between equilibrium prices, we assume that (i) there is no arbitrage so that a direct online price is higher than a wholesale price ($p_D > w$) and the inefficiency of the offline market are higher than the inefficiency of the online market ($t > a$) and (ii) the maximum utility of the customer is higher than the sum of customers' online shopping costs and firms' marginal costs ($V - a - c \geq 0$). Letting $K = (V - a - c)m + a$, then we can compare each retail price of models as follows:

$$p_R^{VN} - p_D^{VN} = \frac{(4a - 3t) + (V - a - c)m}{6} = \frac{-3(t-a) + K}{6}$$
$$p_R^{RS} - p_R^{VN} = \frac{(V - a - c)m + a}{12} = \frac{K}{12}$$
$$p_R^{RS} - p_D^{VN} = \frac{(3a - 2t) + (V - a - c)m}{4} = \frac{-2(t-a) + K}{4}.$$

Then, we can classify three different types of relationship between retail prices according to the difference between t and a as follows:

(i) If $(t - a) \leq \frac{K}{3}$, $\quad p_R^{MS} \geq p_R^{VN} \geq p_D^{VN}$

(ii) If $\frac{K}{3} \leq (t - a) \leq \frac{K}{2}$, $\quad p_R^{RS} \geq p_D^{VN} \geq p_R^{VN}$

(iii) If $\frac{K}{2} \leq (t - a)$, $\quad p_D^{VN} \geq p_R^{RS} \geq p_R^{VN}$

Also, we compare optimal prices in the price-matching model with others in various models, such as the manufacturer Stackelberg leader, the vertical Nash and the retailer Stackelberg leader models. The profit margin of the price-matching model is $p_D^{PM} - w^{PM} = \frac{(V-c)m+(1-m)(t-2a)}{4m}$, and the price difference between online prices is $p_D^{PM} - p_D^{MS} = \frac{(V-c)m+2a-t(1+m)}{4m}$, and the price difference between the online price in the price-matching model and the offline retail price in the retailer Stackelberg leader model is $p_D^{PM} - p_R^{RS} = \frac{(1-m)+\{(V-a-c)m-(t-2a)\}}{4}$. Then, we can classify the relationships between the price-matching strategy model and other models according to the difference between t and a as follows:

(vi) *if* $(t - a) \leq \frac{K}{1+m}$, $\quad p_D^{PM} = p_R^{PM} \leq p_D^{MS}$

(vii) *if* $\frac{K}{1+m} \leq (t - a) \leq K + a$, $\quad p_R^{RS} \geq p_D^{PM} = p_R^{PM} \geq p_D^{MS}$

(viii) *if* $K + a \leq (t - a) \leq \frac{K}{1-m}$, $\quad p_D^{PM} = p_R^{PM} \geq p_R^{RS}$

(ix) *if* $\frac{K}{1-m} \leq (t - a)$, *arbitrage.*

Table 2 shows how equilibrium prices are changed according to the difference between the inefficiency of the online and offline markets (t and a).

As shown in Table 2, generally as the differences of the inefficiency between offline and online markets (t-a) are small, offline prices tend to be higher than online retail prices. However, when the differences of the inefficiency between offline and online markets (t-a) are large (or offline transaction costs are relatively higher than online transaction

Table 2 Pricing structure of various models

The difference of the market inefficiency	Comparison of prices
$(t-a) \le 0$	Arbitrage exist because $p_D \le w$
$0 \le (t-a) \le \frac{K}{3}$	$p_R^{MS} = p_R^{RS} \ge p_R^{VN} \ge p_D^{MS} = p_D^{VN} = p_D^{RS} \ge p_R^{PM} = p_D^{PM} \ge w^{MS} = w^{PM} \ge w^{VN} \ge w^{RS}$
$\frac{K}{3} \le (t-a) \le \frac{K}{2}$	$p_R^{MS} = p_R^{RS} \ge p_D^{MS} = p_D^{VN} = p_D^{RS} \ge p_R^{VN} \ge p_R^{PM} = p_D^{PM} \ge w^{MS} = w^{PM} \ge w^{VN} \ge w^{RS}$
$\frac{K}{2} \le (t-a) \le \frac{K}{1+m}$	$p_D^{MS} = p_D^{VN} = p_D^{RS} \ge p_R^{MS} = p_R^{RS} \ge p_R^{VN} \ge p_R^{PM} = p_D^{PM} \ge w^{MS} = w^{PM} \ge w^{VN} \ge w^{RS}$
$\frac{K}{1+m} \le (t-a) \le a+K$	$p_D^{MS} = p_D^{VN} = p_D^{RS} = p_R^{MS} = p_R^{RS} = p_R^{PM} = p_D^{PM} \ge p_R^{VN} \ge w^{MS} = w^{PM} \ge w^{VN} \ge w^{RS}$
$a+K \le (t-a) \le \frac{K}{1-m}$	$p_R^{PM} = p_D^{PM} \ge p_D^{MS} = p_D^{VN} = p_D^{RS} \ge p_R^{MS} = p_R^{RS} \ge p_R^{VN} \ge w^{MS} = w^{PM} \ge w^{VN} \ge w^{RS}$
$\frac{K}{1-m} \le (t-a)$	Arbitrage exists because $p_R \le w$

costs), online retail prices tend to be higher than offline retail prices. Furthermore, we find that a price in the price-matching model is the highest when the differences of the inefficiency between offline and online markets (*t-a*) are large and the lowest when the differences of the inefficiency between offline and online markets (*t-a*) are small.

The pattern in Table 2 shows that the price in the price-matching model increases as online shopping becomes more convenient, which means that offline transaction costs (t) are higher than online transaction costs (a) from the perspective of the customer. If offline transaction costs are high and online shopping is more convenient, the retailer has less advantage in the offline market. So, a manufacturer sets its prices high at the direct channel. Thus, a price in the price-matching model is the highest, which implies that when a manufacturer has more power and offline transaction costs (t) are relatively high, the manufacturer uses an existing retailer channel with a high pricing strategy at both offline and online markets in order to get more profits from its direct online channel. However, when offline transaction costs (t) are relatively low and a retailer has more advantages in the offline market, the manufacturer may use a price-matching strategy by lowering its prices and aims to eventually drive the retailer out of the market.

For sequential decision models such as the Stackelberg leader and follower model, the price for the retailer is high when it is compared to the direct channel when offline transaction costs (t) are low. However, the price for the retailer is low when it is compared to the direct channel when the offline transaction costs (t) are high and online transaction costs (a) are low. Also for the vertical Nash model, a retail price is lower than a direct channel price when online shopping is less convenient (t is low or a is high), which is consistent with Chun and Kim's [8] result.

4.2 Optimal marketing channel strategies

We obtained the profits of a manufacturer for different models using equilibrium prices. Then, we produced the profits of four hybrid marketing channel models using a numerical analysis. To find an optimal channel strategy, we compared the profits of the hybrid channel models where the manufacturer adds the direct online channel with the basic model[4] where a manufacturer does not use an online channel and sells its products through its existing offline retail channel only. Table 3 shows the procedure of numerical analysis with a numerical example when a manufacturer acts as a market leader.

4.2.1 Online transaction costs (*a*) and the size of the offline market (*m*)

For example, we compared other market power models with the basic model, when $V=30$, $c=15$, $t=2.5$. In the basic model where a manufacturer does not use an online channel, the manufacturer had profits of 11.25.

Table 4 shows the profits of the manufacturer when it acts as a Stackelberg leader, when $V=30$, $c=15$, $t=2.5$ for a and m. The 'none' areas denote cases where optimal solutions cannot be derived because assumptions are not viable. The bold numbers denote areas where a manufacturer has more profits when it adds an online channel to sell products than when it sells goods through an existing offline channel only. Also bold underlined numbers represent cases where a manufacturer has the maximum profit for each different a. As shown in Table 4, the manufacturer receives more profits as a (the online inconvenient cost) decreases for all m. If we can regard a as a relative online customer cost to offline customer cost (t), the manufacturer adds an online channel when online shopping is more convenient. Table 4 shows that a manufacturer will launch a new online channel (i) when online shopping is more convenient, (ii) the size of the online market $(1-m)$ is very large when the online

[4] The basic model can be classified into three types according to the market power models (a Stackelberg leader, a vertical Nash and a Stackelberg follower). We compared the profits of the basic model where a manufacturer acts as a Stackelberg leader with those of other hybrid models, which did not affect the main result.

Table 3 The numerical example when a manufacturer acts as a market leader

Steps of the procedure	A numerical example of the manufacturer leader model
Step 1: Find equilibrium conditions and select parameters satisfying those conditions (Profit margin and market demands should be greater than zero)	We found optimal solutions for the manufacturer leader model from the analytical model, and select one ($V=30$, $c=15$, $t=2.5$ $a=2$, $m=0.25$) among some parameters satisfying equilibrium conditions. Then, we obtained numerical values for equilibrium prices by substituting the selected parameters for each price as follows: $w = \frac{t}{2m} + \frac{V+c-t}{2} = \frac{2.5}{2\times 0.25} + \frac{30+15-2.5}{2} = 26.3 > 0.$ $p_d = \frac{t}{2m} + \frac{V+c-a}{2} = \frac{2.5}{2\times 0.25} + \frac{30+15-1}{2} = 27.0 > 0.$ $p_r = \frac{t}{2m} + \frac{V+c-t}{2} + \frac{m(V-c-a)+a}{4} = \frac{2.5}{2\times 0.25} + \frac{30+15-2.5}{2} + \frac{0.25\times(30-15-1)+1}{4} = 27.4 > 0$ We also checked if the selected parameters satisfied other equilibrium conditions, such as profit margin and market demands (i) Profit margin $w - c = \frac{t}{2m} + \frac{V+c-t}{2} - c = \frac{2.5}{2\times 0.25} + \frac{30+15-2.5}{2} - 15 = 26.3 - 15 = 11.3 > 0.$ $p_d - c = \frac{t}{2m} + \frac{V+c-a}{2} - c = \frac{2.5}{2\times 0.25} + \frac{30+15-1}{2} - 15 = 12.0 > 0.$ $p_r - w = \frac{t}{2m} + \frac{V+c-t}{2} + \frac{m(V-c-a)+a}{4} - w = \frac{2.5}{2\times 0.25} + \frac{30+15-2.5}{2} + \frac{0.25\times(30-15-1)+1}{4} - 11.3 = 16.1 > 0.$ (ii) Offline and online demands $D_R = (1-m)\left(\frac{p_d + a - p_r}{t}\right) + (m)\frac{V-p_r}{t} = (1-0.25)\left(\frac{27+1-27.4}{2.5}\right) + (0.25)\frac{30-27.4}{2.5} = 0.45 > 0.$ $D_D = (1-m)\left(1 - \frac{p_d + a - p_r}{t}\right) = (1-0.25)\left(1 - \frac{27+1-27.4}{2.5}\right) = 0.18 > 0.$
Step 2: Produce the profits of a bricks-and-mortar model with the selected parameters	We obtained the profits of a bricks-and-mortar model with the selected parameters as follows: $\pi_M^B = \frac{(V-c)^2}{8t} = \frac{(30-15)^2}{8\times(2.5)} = 11.25$
Step 3: Produce the profits of four hybrid channel models with the selected parameters	To compare the performance of a bricks-and-mortar model with four hybrid channel models, we obtained the profits of the hybrid channel models with the selected parameters as follows: $\Pi_M = m(w-c)\left(\frac{V-p_r}{t}\right) + (1-m)(w-c)\left(\frac{p_d+a-p_r}{t}\right) + (1-m)(p_d-c)\left(1-\frac{p_d+a-p_r}{t}\right)$ $= 0.25(30-15)\left(\frac{30-27.4}{t}\right) + (1-0.25)(30-15)\left(\frac{27.0+1-27.4}{t}\right) + (1-0.25)(27-15)\left(1-\frac{27.0+1-27.4}{t}\right) = 11.81.$ In the same way, we produced the profits of other hybrid channel models, such as the market follower, Nash-game and price-matching models
Step 4: Compare the profits of a bricks-and-mortar model with other hybrid channel models and find an optimal channel strategy and its conditions	We compared the profits of a bricks-and-mortar model with a manufacturer leader model. If $\Pi_M > \pi_M^B$, then the manufacturer chooses a hybrid channel strategy. In this numerical example, $\pi_M^B = 11.25 < \Pi_M = 11.81$. Thus, the manufacturer chooses a hybrid channel strategy. Next, we find its optimal conditions. For example, when $a=1$, the manufacturer always chooses a hybrid channel strategy. However, when a becomes high, the manufacturer selects a bricks-and-mortar strategy instead of the hybrid channel strategy as shown in Fig. 2. In the same way, we can compare the performance of a bricks-and-mortar model with other models

Table 4 The profits of the manufacturer leader model

m	*a*										
	0.01	1.00	2.00	3.00	4.00	5.00	6.0	7.0	8.0	9.0	10.0
0.1	None	None	None	None	None	None	None	None	None	None	None
0.2	**12.54**	**11.95**	**11.46**	11.06	10.75	10.55	10.48	None	None	None	None
0.3	**12.43**	**11.82**	**11.29**	10.86	10.51	10.25	10.09	10.02	None	None	None
0.4	None	**12.01**	**11.48**	11.03	10.66	10.38	10.18	10.07	None	None	None
0.5	None	None	**11.71**	**11.27**	10.91	10.62	10.41	10.27	10.21	None	None
0.6	None	None	None	**11.47**	11.13	10.86	10.65	10.51	10.43	None	None
0.7	None	None	None	None	**11.30**	11.06	10.88	10.74	10.66	10.63	None
0.8	None	None	None	None	**11.38**	11.20	11.06	10.95	10.88	10.85	None
0.9	None	None	None	None	None	**11.27**	11.18	11.12	11.08	11.06	None
1	None	None	None	None	None	11.25	11.25	11.25	11.25	11.25	11.25

None denotes non-feasible area

Table 5 Profits of the manufacturer in the vertical Nash model

m	*a*										
	0.01	1.00	2.00	3.00	4.00	5.00	6.0	7.0	8.0	9.0	10.0
0.1	None	None	None	None	None	None	None	None	None	None	None
0.2	**12.49**	**11.88**	**11.34**	10.90	10.54	None	None	None	None	None	None
0.3	**12.33**	**11.68**	11.10	10.61	10.21	9.90	None	None	None	None	None
0.4	**12.43**	**11.78**	11.20	10.69	10.27	9.94	None	None	None	None	None
0.5	**12.49**	**11.87**	**11.31**	10.82	10.41	10.07	9.80	None	None	None	None
0.6	None	**11.85**	**11.34**	10.89	10.51	10.19	9.94	None	None	None	None
0.7	None	None	11.24	10.86	10.53	10.27	10.04	None	None	None	None
0.8	None	None	10.99	10.71	10.47	10.26	10.10	None	None	None	None
0.9	None	None	None	10.43	10.29	10.18	10.08	10.01	None	None	None
1	None	None	None	10	10	10	10	10	None	None	None

Table 6 Profits of the manufacturer follower

m	a										
	0.01	1.00	2.00	3.00	4.00	5.00	6.0	7.0	8.0	9.0	10.0
0.1	None	None	None	None	None	None	None	None	None	None	None
0.2	**12.24**	**11.59**	10.93	10.33	9.79	9.32	8.91	none	None	None	None
0.3	**11.85**	11.15	10.42	9.77	9.18	8.65	8.21	7.81	None	None	None
0.4	None	10.93	10.18	9.51	8.90	8.36	7.88	7.47	None	None	None
0.5	None	None	9.90	9.25	8.65	8.12	7.65	7.25	6.90	None	None
0.6	None	None	None	8.87	8.32	7.84	7.40	7.03	6.71	None	None
0.7	None	None	None	None	7.88	7.46	7.10	6.78	6.50	6.27	None
0.8	None	None	None	None	7.28	6.98	6.70	6.46	6.26	6.09	None
0.9	None	None	None	None	None	6.36	6.21	6.08	5.97	5.87	None
1	None	None	None	None	None	5.62	5.62	5.62	5.62	5.62	5.62

cost (a) is low and (iii) the size of the offline market (m) is moderate when the online cost (a) is high.

Table 5 shows the profits of the manufacturer in the vertical Nash model. As shown in Table 4, the profits of the manufacturer increase, as online shopping is more convenient (a decreases). But when the offline customer costs (t) are higher than the online customer costs (a), the manufacturer will not enter the online market. Also, as we expected, the profits of the manufacturer leader model are higher than those of the vertical Nash model.

Table 6 shows the profits of the manufacturer follower model. As shown in Table 6, the profits of the manufacturer decrease as a and m increase. This implies that, when a manufacturer acts as a Stackelberg follower, the manufacturer

Table 7 Profits of the price-matching strategy model

m	a										
	0.01	1.00	2.00	3.00	4.00	5.00	6.0	7.0	8.0	9.0	10.0
0.1	None	None	None	None	None	None	None	None	None	None	None
0.2	None	None	None	None	None	None	None	None	None	None	None
0.3	**11.62**	10.15	None	None	None	None	None	None	None	None	None
0.4	**11.39**	10.00	8.11	None	None	None	None	None	None	None	None
0.5	**11.28**	10.05	8.50	None	None	None	None	None	None	None	None
0.6	11.22	10.21	8.98	None	None	None	None	None	None	None	None
0.7	11.20	10.42	9.51	None	None	None	None	None	None	None	None
0.8	11.21	10.68	10.07	None	None	None	None	None	None	None	None
0.9	11.22	10.95	10.65	None	None	None	None	None	None	None	None
1	11.25	11.25	11.25	None	None	None	None	None	None	None	None

Table 8 Manufacturer's profits according to various models

m	*a*					
	Models	0.01	0.1	1	2	3
0.1						
Profits of models	Bricks and Mortar	11.25	11.25	11.25	11.25	11.25
	Manufacturer Leader	None	None	None	None	None
	Vertical Nash	None	None	None	None	None
	Manufacturer Follower	None	None	None	None	None
	Price-matching Strategy	None	None	None	None	None
0.25						
Profits of models	Bricks and Mortar	11.25	11.25	11.25	11.25	11.25
	Manufacturer Leader	**12.41**	**12.35**	**11.81**	**11.29**	10.87
	Vertical Nash	**12.33**	**12.28**	**11.70**	11.14	10.67
	Manufacturer Follower	**12.06**	**11.99**	**11.30**	10.60	9.97
	Price-matching Strategy	**11.94**	**11.83**	10.37	None	None
0.5						
Profits of models	Bricks and Mortar	11.25	11.25	11.25	11.25	11.25
	Manufacturer Leader	None	None	None	**11.71**	**11.27**
	Vertical Nash	**12.49**	**12.43**	**11.87**	11.31	10.82
	Manufacturer Follower	None	None	None	9.90	9.25
	Price-matching Strategy	**11.39**	**11.28**	10.05	8.5	None
0.9						
Profits of models	Bricks and Mortar	11.25	11.25	11.25	11.25	11.25
	Manufacturer Leader	None	None	None	None	None
	Vertical Nash	None	None	None	None	10.42
	Manufacturer Follower	None	None	None	None	None
	Price-matching Strategy	**11.26**	11.22	10.95	10.65	None

adds an online channel when online shopping is more convenient (when *a* is low) and the size of the online market is very large (when *m* is low).

As shown in Tables 4, 5 and 6, the manufacturer will have more chances to add an online channel when it acts as a Stackelberg leader rather than when it acts as a Stackelberg follower. Also, as we expected, the profits of the manufacturer follower model are lower than those of the vertical Nash model.

As shown in Table 7, the manufacturer finds it difficult to make a profit when it adds an online channel except when *a* is very low. Interestingly this price-matching strategy shows the worst case among the models we analysed from the perspective of the profit gained. Cattani et al.'s [4] showed that a price-matching strategy could alleviate the channel conflict when the manufacturer starts to sell products online. Seemingly, the price-matching strategy can be regarded as a strategic choice for the manufacturer who wants to sell

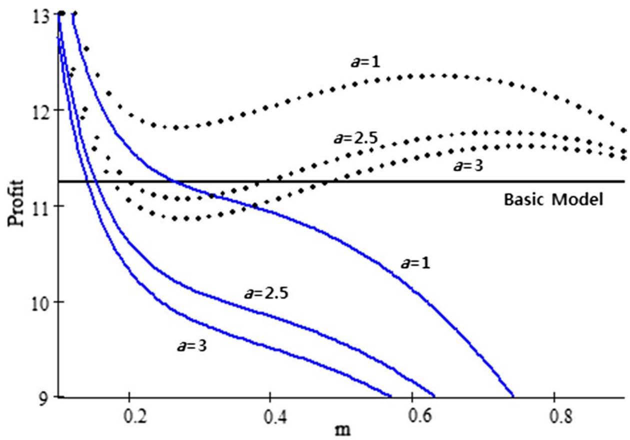

Fig. 2 Profit curves of a manufacturer according to a and m

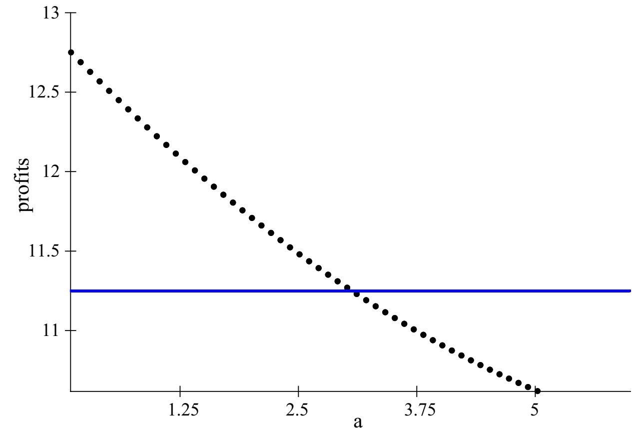

Fig. 4 Manufacturer's profits when $V=30$, $c=15$, $t=2.5$ and m is fixed at ½

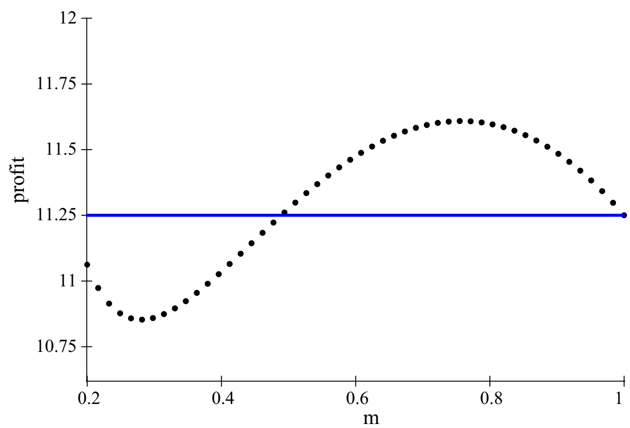

Fig. 3 Manufacturer's profits when $V=30$, $c=15$, $t=2.5$ and a is fixed at 3

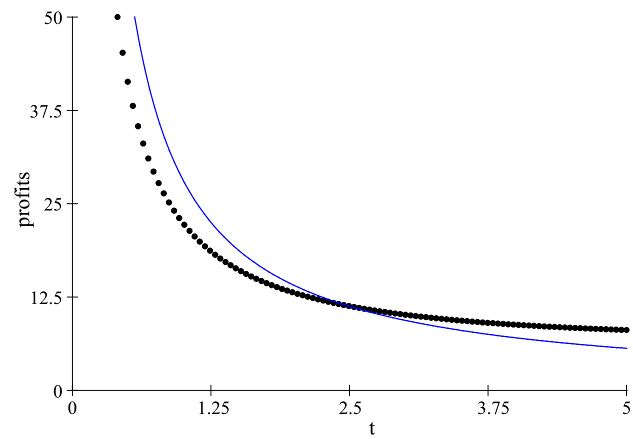

Fig. 5 Case of changing t with fixing $a=3$ and $m=½$

products online and offline at the same time to alleviate channel conflict. That is, it is quite necessary for retailers to increase the quality of the purchase experience that goes beyond the direct channel [5]. However, based on our results, it will lead to a lower retail price and create low margins for retailer so that there is a lower profit for both a retailer and manufacturer when the difference of customer costs between offline and online is low.

Table 8 compares the profits of the manufacturer in the four hybrid channel models and shows that a manufacturer does not choose a hybrid channel strategy when online customer costs (a) are relatively high and the size of the online market ($1-m$) is relatively small.

Figure 2 shows the resulting profits of manufacturer leader and follower models. The blue lines represent cases when a manufacturer acts as a Stackelberg follower and the black dotted lines denote cases when a manufacturer acts as a Stackelberg leader. As we expected, the profits of the manufacturer Stackelberg leader model are higher than that of the follower model. This figure shows that as a increases the profits of hybrid models decrease. Also, the profits of the manufacturer follower model decrease as m increases, while the profits of the manufacturer leader model tends to increase as m increases at a certain range.

4.2.2 Sensitivity analysis

We focussed on a case when a manufacturer acts as a Stackelberg leader to see how various factors, such as the size of the offline market (m), online customer costs (a) and offline customer costs (t) affect the profits of the manufacturer.

(1) Market size

We compared the resulting profits of two models (the basic model and manufacturer leader model) when a is fixed

Table 9 A manufacturer's hybrid channel strategy according to market power models

Online market size (1 – m)	Online cost (a)		
	Low	Medium	High
Low	All models	ML model/ Nash model	None
Medium	ML model/Nash model	ML model	None
High	None	None	ML model

ML model denotes the manufacturer Stackelberg leader model and 'None' represents none feasible area

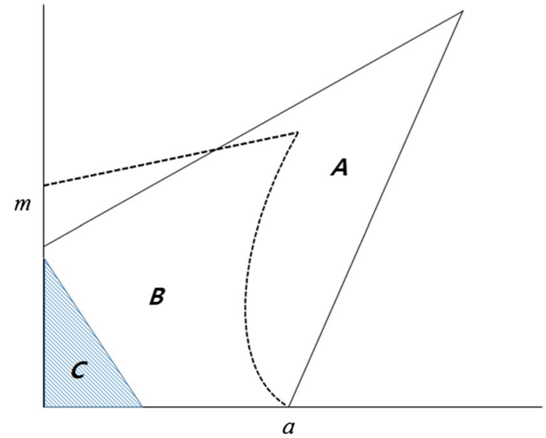

Fig. 6 Areas of hybrid marketing channel strategies (*A* denotes a Stackelberg leader model, *B* denotes a Nash model and *C* denotes a Stackelberg follower model)

at 3 to see how m could affect the profits of the manufacturer using online and offline channels, as shown in Fig. 3. The dotted curve denotes the profits of the hybrid model, while the blue solid line represents the profits of the basic model when a manufacturer uses an offline channel only.

Figure 3 implies that a manufacturer adds an online channel when m is larger than a certain point, which means that, when a manufacturer acts as a Stackerlberg leader, it needs a certain number of offline customers.

(2) Online customer cost (a)

Figure 4 shows the resulting profits of two models according to customers' online costs when m is fixed at ½. The dotted curve denotes the profits of the hybrid model when a manufacturer uses both channels, while the blue line represents the profits when a manufacturer uses an offline channel only. As shown in Fig. 4, as online costs (a) decrease the profits of the hybrid model increase, which means that, as consumers experience the greater convenience of online shopping, the manufacturer tends to launch its online business. Figure 4 supports the results of Table 4, which seemingly implies that when online costs (a) are lower, the profits of the manufacturer with an additional online channel are higher than those of the manufacturer without an online channel.

(3) Offline customer cost (t)

To see the effect of t, Fig. 5 compares the profits of two models when a and m are fixed at 3 and ½, respectively. The black dotted curve denotes the profits of the hybrid model, while the blue solid line curve represents the profits of the basic model.

Figure 5 is closely related to Fig. 4 and shows that, as offline customer costs (t) increase, the profits of the two models decrease, but the profits of the hybrid model decrease less than those of the basic model. It means that, as online shopping becomes more convenient (t increases or a decreases), the manufacturer wants to add an online channel, rather than use the existing offline channel only. This also states that when offline customer costs are relatively lower, a manufacturer does not enter the online market.

5 Concluding remarks and future work

This paper analyses a manufacturer's channel strategies and pricing strategies when it adds an online channel to an existing offline channel and shows some interesting results for a manufacturer's optimal channel strategies. A manufacturer tends to enter an online market as online shopping becomes more convenient, the size of online market is bigger, and it has more market power in a supply chain. Thus, when the online shopping costs are not relatively lower than offline costs, the manufacturer insists on an existing offline channel only to sell its goods. Table 9 shows that when a manufacturer uses a hybrid channel strategy according to market conditions, such as online costs, a (or offline costs, t) and offline market size, m (or online market size, $1 - m$).

As shown in the Table 9, a manufacturer's hybrid strategies depend on online shopping costs and the size of the market. When a manufacturer acts as a Stackelberg follower, the manufacturer chooses a hybrid marketing channel strategy as online shopping costs become very low and the size of the online market is relatively very large. When a manufacturer acts as a Stackelberg leader, the manufacturer has more chances to enter the online market. Thus, if a manufacturer has more power than a retailer, the manufacturer can use a hybrid channel strategy even when the online cost is relatively higher. Figure 6 shows the general results when a manufacturer uses a hybrid marketing channel strategy, which is drawn from numerical analysis from Tables 4, 5 and 6.

As shown in Fig. 6, the more a manufacturer has market power, the more a manufacturer has chances to use hybrid channel strategies. For example, when a manufacturer acts as a Stackelberg follower, the manufacturer can choose a hybrid channel strategy under the very low conditions of a and m (or very low online costs and large offline market size).

This paper has also dealt with a price-matching game as Cattani et al.'s [4] manufacturer leader case. This situation covers the scenario when airlines sell their tickets on their websites as well as through less powerful retailers, such as small travel agencies. The results are that a lower wholesale price and less profit for small retailers and small travel agencies means that they are predicted to be pushed out when the offline and online customer cost gap becomes smaller. This paper shows that if a manufacturer perceives that offline market size is relatively larger, a retailer has more advantages in the offline market (or online market costs are relatively high), then the manufacturer may use a price-matching strategy by lowering its prices and aims to eventually drive the retailer out of the market, even though the manufacturer acts as a Stackelberg leader. Cattani et al. [4] assumed the case when a manufacturer has more power and plays the role as a price-setter. Thus, the results will be different when a manufacturer has less power and faces more powerful retailers, such as Amazon or Expedia. For example, this case is very similar to the situation where airlines sell their tickets using dual channels: their website and Expedia's website. When there is a powerful retailer's presence, the study of how the price-matching strategy works will be very interesting. From our numerical analysis, we can expect a result that when a manufacturer acts as a Stackelberg follower (or a manufacturer has less power than a retailer), the manufacturer uses a price-matching strategy rather than a hybrid channel strategy, even when the size of online market is relatively high enough (the size of offline market (m) is not large enough).

Future research is needed on more analysis of the price-matching strategy according to market power and how a manufacturer sets its online prices in a multi-channel situation. Therefore, we need to incorporate the situation where there are powerful retailers [19] because when the retailer has the market power, the outcome will be different from the price-matching of powerful manufacturers [4].

Appendix 1: Proof for the manufacturer Stackelberg leader model

In the first period, a manufacturer anticipates a retailer's reaction function. A retailer's reaction function can be obtained from the retailer's profit function which is given by

$$\Pi_R^{MS} = m\left(p_R^{MS} - w^{MS}\right)\left(\frac{V - p_R^{MS}}{t}\right) + (1-m)\left(p_R^{MS} - w\right)\left(\frac{p_D^{MS} + a - p_R^{MS}}{t}\right).$$

The retailer's reaction function can be derived from the first-order condition as follows:

$$\frac{\partial \Pi_R^{MS}}{\partial p_R^{MS}} = \frac{a + Vm - am + w^{MS} + p_D^{MS} - 2p_R^{MS} - mp_D^{MS}}{t} = 0.$$

From the above condition, the retailer's reaction function is derived as:

$$p_R^{MS} = \frac{a + Vm - am + w^{MS} + p_D^{MS} - mp_D^{MS}}{2}.$$

Using the above reaction function, a manufacturer chooses a wholesale price and a direct online price from the first-order conditions of the manufacturer's profit maximization problem. The manufacturer's profit function is given by:

$$\Pi_M^{MS} = m\left(w^{MS} - c\right)\left(\frac{V - p_R^{MS}}{t}\right) + (1-m)\left(w^{MS} - c\right)\left(\frac{p_D^{MS} + a - p_R^{MS}}{t}\right) + (1-m)\left(p_D^{MS} - c\right)\left(1 - \frac{p_D^{MS} + a - p_R^{MS}}{t}\right).$$

The first-order conditions are:

$$\frac{\partial \Pi_M^{MS}}{\partial w^{MS}} = -\frac{am - Vm - a - cm + 2w^{MS} - 2p_D^{MS} + 2mp_D^{MS}}{2t} = 0$$

$$\frac{\partial \Pi_M^{MS}}{\partial p_D^{MS}} = -\frac{(1-m)\left(a - 2t - Vm + am - cm - 2w^{MS} + 2p_D^{MS} + 2mp_D^{MS}\right)}{2t} = 0.$$

From the above equations wholesale and online prices are obtained as follows:

$$w^{MS^*} = \frac{t}{2m} + \frac{V + c - t}{2}, \quad p_D^{MS^*} = \frac{t}{2m} + \frac{V + c - a}{2}.$$

Then, in the second period, the retailer finds an optimal retail price by using the manufacturer's wholesale and direct online prices as follows:

$$p_R^{MS^*} = \frac{t}{2m} + \frac{V + c - t}{2} + \frac{a}{4} + \frac{V - c - a}{4}m.$$

Appendix 2: Proof for the retailer Stackelberg leader model

A retailer, as a market leader, takes the manufacturer's reaction function into account for its own retail price decisions. So, a retailer uses a manufacturer's reaction function, which is derived from the manufacturer's profit maximization problem in the second period. The manufacturer decides its wholesale and online prices anticipating the retailer's margin, $k = p_r^N - w$. Then, the manufacturer's profit function is given by:

$$\Pi_M^{RS} = m\left(w^{RS} - c\right)\left(\frac{V - p_R^{RS}}{t}\right) + (1 - m)\left(w^{RS} - c\right)\left(\frac{p_D^{RS} + a - p_R^{RS}}{t}\right) + (1 - m)\left(p_D^{RS} - c\right)\left(1 - \frac{p_D^{RS} + a - p_R^{RS}}{t}\right).$$

Where subscript, RS, denotes the case where a retailer acts as a Stackelberg leader.Here,$p_R^{RS} = k + w$, then this profit function is rewritten as:

$$\Pi_M^{RS} = m\left(w^{RS} - c\right)\left(\frac{V - \left(k + w^{RS}\right)}{t}\right) + (1 - m)\left(w^{RS} - c\right)\left(\frac{p_D^{RS} + a - \left(k + w^{RS}\right)}{t}\right)$$
$$+ (1 - m)\left(p_D^{RS} - c\right)\left(1 - \frac{p_D^{RS} + a - \left(k + w^{RS}\right)}{t}\right).$$

Then, a manufacturer's reaction function can be derived from the following first-order conditions:

$$\frac{\partial \Pi_M^{RS}}{\partial w^{RS}} = \frac{\left(a - k + Vm - am + cm - 2w + 2p_D^{RS} - 2mp_D^{RS}\right)}{t} = 0$$
$$\frac{\partial \Pi_M^{RS}}{\partial p_D^{RS}} = -\frac{\left(a - k - t - 2w + 2p_D^{RS}\right)}{t}(1 - m) = 0.$$

Thus, reaction functions are:

$$w^{RS} = \frac{\left(t + Vm + cm - mt - mp_R^{RS}\right)}{m}$$
$$p_D^{RS} = \frac{(t + Vm - am + cm)}{2m}.$$

Anticipating these reactions, the retailer maximizes its profits in the first period. The retailer's profit function is given by:

$$\Pi_R^{RS} = m(p_R^{RS} - w^{RS})\left(\frac{V - p_R^{RS}}{t}\right)$$
$$+ (1 - m)(p_R^{RS} - w^{RS})\left(\frac{p_D^{RS} + a - p_R^{RS}}{t}\right).$$

The reaction function is derived from the first-order condition as follows:

$$\frac{\partial \Pi_R^{RS}}{\partial p_R^{RS}} = \frac{\left(2t + 2Vm + am + 2cm - 2mt - 4mp_R^{RS} + Vm^2 - am^2 - cm^2\right)}{mt} = 0.$$

Then, optimal prices are obtained as follows:

$$w^{RS*} = \frac{\left(2t + 2Vm + 2cm - am - 2mt - Vm^2 + am^2 + cm^2\right)}{4m}$$
$$p_D^{RS*} = \frac{(t + Vm - am + cm)}{2m}$$
$$p_R^{RS*} = \frac{\left(2t + 2Vm + 2cm + am - 2mt + Vm^2 - am^2 - cm^2\right)}{4m}.$$

Appendix 3: Proof for the vertical Nash Model

A manufacturer conditions its wholesale and online prices on the retail margin $k = p_r^N - w$. Then, the manufacturer's profit function is given by:

$$\Pi_M^N = m\left(w^N - c\right)\left(\frac{V - p_R^N}{t}\right) + (1-m)\left(w^N - c\right)\left(\frac{p_D^N + a - p_R^N}{t}\right) + (1-m)\left(p_D^N - c\right)\left(1 - \frac{p_D^N + a - p_R^N}{t}\right),$$

where N denotes vertical Nash model.

The first-order conditions are:

$$\frac{\partial \Pi_M^N}{\partial w^N} = a + Vm - am + cm - w^N + 2p_D^N - p_R^N - 2mp_D^N = 0$$
$$\frac{\partial \Pi_M^N}{\partial p_D^N} = a - t - w^N + 2p_D^N - p_R^N = 0.$$

From the above equations we obtain the following reaction functions:

$$w^N = \frac{1}{m}\left(t + Vm + cm - mt - mp_R^N\right), \quad p_D^N = \frac{1}{2}(p_R^N - a + t + w^N).$$

The retailer's profit function is given by:

$$\Pi_R^N = m\left(p_R^N - w^N\right)\left(\frac{V - p_R^N}{t}\right) + (1-m)\left(p_R^N - w^N\right)\left(\frac{p_D^N + a - p_R^N}{t}\right).$$

The retailer chooses its retail price to maximise its profit function by anticipating the manufacturer's wholesale price and direct online prices. The first-order condition is given by:

$$\frac{\partial \Pi_R^N}{\partial p_R^N} = a + Vm - am + w^N + p_D^N - 2p_R^N - mp_D^N = 0.$$

From the first-order condition, we obtain the following reaction function as follows:

$$p_R^N = \frac{a + Vm - am + w^N + p_D^N - mp_D^N}{2}.$$

Then, optimal prices are derived from the above reaction functions as follows:

$$w^{N*} = \frac{3Vm - Vm^2 - am + 3cm + 3t - 3mt + am^2 + cm^2}{6m}$$
$$p_D^{N*} = \frac{Vm + t - am + cm}{2m}$$
$$p_R^{N*} = \frac{3Vm + Vm^2 + am + 3cm + 3t - 3mt - am^2 - cm^2}{6m}.$$

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