Advances in Economics, Business and Management Research, volume 85
2nd International Conference on Economy, Management and Entrepreneurship (ICOEME 2019)

Product Differentiation Strategy in Dual-channel Supply Chain Faced with Free Riders

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***Abstract*—With the rapid development of the Internet technology, an increasing number of firms operate dual-channel structure. Considering of the complexity and dynamic in the dual-channel market, it is necessary to carry out a simulation study. Consumers, who have access to both the physical retail store and the Internet channel, are potential free riders. The firm has a strategy to differentiate products in dual channels. It is found that (i) when consumers have little ex-ante product information, they would be highly motivated to consume in-store service. It is true in the situation that when firms promote innovative products to the market, consumers have to spend more energy to obtain relevant information and experience new products in physical stores. (ii) After in-store service, consumers would free ride to buy online, if the online searching cost is low, regardless of the product valuation. (iii) Firms usually try the best to please junior members and provide higher preferential benefit for them than that for senior members. (iv) When the price gap between online and offline channels is high, the offline profit decreases, but the online profit increases. The number of free riders is independent of the price gap, but decreases with the degree of product differentiation. This paper further considers the interaction between consumers and supply chain members, and uses multi-agent simulation to depict consumer behavior in multiple periods. The simulation results and sensitivity analyses indicate that (i) when consumers have enough information of products (e.g. daily necessaries), they tend to buy online directly instead of visiting the physical store. On the contrast, visiting is necessary when products are innovative, new high-tech or needed to be experienced, like perfume and apparel. (ii) Firms should reduce the in-store service cost and set the same price of the products in dual channels, to increase own profit. (iii) Firms should take action (e.g. advertising) to enhance consumer familiarity about products (iv) Product differentiation strategy weakens consumers' free riding behavior and improves firms' profit.**

***Keywords*—free riding; product differentiation strategy; dual-channel supply chain; multi-agent simulation**

I. INTRODUCTION

An increasing number of firms develop dual-channel supply chains owing to the power of the Internet. The introduction of an online channel expands the manufacturer's market while enhances channel conflict, which harms the benefit of supply chain members. The online price is usually lower than the in-store price, because the operation costs online is low (Brynjolfsson and Smith, 2000; Carlton and Chevalier, 2001; Wu et al., 2004; Kucuk and Maddux, 2010). Consumers prefer the online channel for discounts. However, besides to prices, there are many other crucial attributes of products, such as taste and feel, which cannot be completely distinguished until the consumer visits stores and consumes service (Lal and Sarvary, 1999). Therefore, the phenomenon of *free riding* emerges in dual-channel supply chains. Physical retailers engage in service activities but the Internet channel benefits from the final sale. The consumers, who take full advantages of the retailer's in-store service and then switch to the Internet channel to purchase at discounts, are called *free riders*. Free riding behavior not only erodes the service motivation of retailers, but also harms consumers' satisfaction and demands in turn. Eventually, the firm suffers a lot. As free riding problems are getting worse among consumers due to the rapid development of the Internet technology, much attention needs to be paid to this urgent issue.

According to Chiang et al. (2003), the root cause of channel conflict is that dual-channel product positioning and target consumers are similar. To avoid channel cannibalization, some firms recently differentiate the products online and offline. For instance, SHARP shows and sells innovative and high-tech products in physical shopping malls, but ordinary products online. CHOW TAI FOOK, a jewelry company in Hong Kong, promotes specially designed products online with simple styles and materials to cater young consumers, who prefer online shopping and have limited financial capacity. These two firms' differentiation strategies are the exact business strategies that this paper examines.

The current paper studies product differentiation strategy in dual-channel supply chain face with free riders. Consumers have incomplete information of products before consuming service, and are heterogeneous among product valuations. This paper focuses on the interaction between heterogeneous consumers and considers social effect, and employs multi-agent simulations and sensitivity analysis to support the robustness of theoretical model and obtain some management implications. (i) When consumers have little information of products, they would consume the in-store service. Then they decide to buy online or offline depending on the online searching cost instead of the product valuation.

(ii) When the price gap is high, consumers prefer the online channel, but their free riding behavior is independent of the price gap. (iii) The firm's profit decreases with the in-store service, but increases with consumer familiarity about products. (iv) When the degree of product differentiation is high, the number of free riders is low and the firm's profit is high.

II. LITERATURE REVIEW

Early studies about free riding mainly focus on its disadvantages and indicating that retailers should use various devices to keep consumers from free riding (see Telser, 1960; Mittelstaedt, 1986; singly and Williams, 1995; Antia et al., 2004). In the past decade, several researches show that free riding is not always harmful. For example, Shin (2007) consider two asymmetric retailers in terms of their service provision and find that both free-riding and service-providing retailers can benefit from free riding because it softens the price competition. Bernstein et al. (2009) design a kind of high-cost and service-oriented stores which are purposely set up to educate consumers about products. They found that manufacturers benefit most from operating this kind of stores when a large portion of the market requires information about the products and when most consumers' valuations for the products increase after visiting. Kucuk and Maddux (2010) investigate free riding in terms of consumer pre-purchase activities and their empirical findings indicate that full-service retailers' beliefs about online consumers' choice of purchase outlet are predominantly influenced by online retailer prices rather than availability of a variety of products on the Internet. Xing and Liu (2012) consider two retailers where one offers a lower price and free-rides another's sales effort. To achieve sales effort coordination, several contracts are designed. Their numerical analysis shows that the selective rebate with price match contract has the best system performance, unless the proportion of free-riding consumers is very small. However, the majority of the papers above are about free riding problems among the same products between different retailers. Few considers differentiated products in a dual-channel supply chain as the current paper does. A relevant research is an empirical analysis from Carlton and Chevalier (2001). They consider the products position strategy in dual channels and point out that products should be different to weaken the negative effects of free riding. The results of multi-agent simulation experiments suggest that the product differentiation decreases not only free riders but also dual channels' demand, but eventually benefit the firm as Carlton and Chevalier (2001) stated.

This paper considers consumers' heterogeneity among product valuations and focuses on their interaction with each other; and simulates a dual-channel supply chain and depicts consumers' purchasing behavior. The multi-agent simulation method is widely used in many researches to solve highly dynamic and complex issues (Giannakis and Louis, 2011; Amini et al., 2012; Groves et al., 2014; Jiang et al., 2014; Jiang et al., 2016). Each consumer is simulated into an agent. Multiple agents interact with neighbors (agents) and make purchasing decisions. To test the sensitivity of simulation results, ANOVA and the non-parametric test are employed. Further, the simulation results are compared with the theoretical results to ensure the robustness.

The main contributions of this paper are stated as follows. Firstly, consumers' self-perceived utilities are combined with social effects. That is, consumers' purchasing decisions are influenced by relatives and friends. Besides, consumer heterogeneity and the interaction among consumers and supply chain members are considered. That makes our model settings much more match the reality. Secondly, this paper focuses on the sales of differentiated products in dual channels and obtains some relevant results and management implications. Furthermore, not only theoretical method, but also multi-agent simulation and sensitivity analyses are employed for the model, which guarantee the robustness of results.

III. THE BASIC MODEL

There is a manufacturer selling products in a dual-channel supply chain consisting of an offline retail channel and an online channel. Consumers can free ride the service from the physical retail store and then turn to the online channel for purchases. The firm offers different deals in each channel, which has been proved effective to erode the free riding impact (Heitz-Spahn, 2013). The main research aim is to help the firm to optimize the dual-channel product differentiation strategy when facing with free riders.

"Table I" summarizes the symbols and definitions of parameters necessary for the profit model.

TABLE I. MODEL SYMBOLS AND DEFINITION

Symbol	Definition
d	Distance of product differentiation between online and offline channels. The higher d is, the more different the products in dual channels are.
s	Unit service cost per visitor.
v	Product valuation.
m	A multiplier used to indicate consumers' incomplete information of products before service. The higher m is, the lower ex-ante product valuation consumers have.
b	Products preference intensity.
t	Physical shopping cost in the retail channel.
h	Total shopping cost of free riding behavior.

According to the study of Xia and Rajagopalan (2009) and Xiao et al. (2014), an assumption is made that the distance of the product differentiation is denoted by d and consumers' preferences for these two channels' products are uniformly distributed in an interval $[0,d]$ with the two kinds of products respectively located at the points 0 and d. There are N consumers in the interval, so the density of the interval is $\frac{N}{d}$. The offline retailer decides the product price in the retail channel p_R and the manufacturer decides the price in the online (Internet) channel p_I to optimize own profit.

Consumers have incomplete products information until they get first-person experience with products in the physical store. That is, a consumer has an ex-ante product evaluation $(1-m)v$, where the multiplier $0<m<1$ is used to indicate his incomplete information of products without the in-store service (Bernstein et al., 2009; Xiong and Chen, 2013). It is not uncommon in the sales of experience products, such as high-tech electronic products, jewelry, fashion apparel, artwork, perfume, etc. The value of mv indicates the loss caused by consumers' incomplete product information. Besides, his location on the preference interval x represents the distance between his ideal product and the offline product; $d-x$ indicates the distance from the online product ($0 \le x \le d$). The intensity of relative preference is denoted by b. Thus, $(d-x)b$ is the loss of utility when the consumers buy a product from the online channel? The utility is $u_I = (1-m)v - p_I - (d-x)b$ when the consumer purchase online directly with incomplete product information. On the contrary, the consumer's valuation of product is v with in-store service, i.e. complete product information. Note that, the retailer cannot reject any service request even if the consumer does not purchase in the retail channel after being served (Shin, 2005; Shin, 2007; Xing and Liu, 2012). The in-store service costs the retailer s per visitor. The visitor also has to pay for the time and effort expended in trying on, taste testing or trying out an electronic product (Wu et al., 2004; Shin, 2007; Guo and Zhang, 2012), which is defined by shopping cost t. A cap is added to the utility to represent consumer utility with in-store service. So the utility obtained in the retail channel is $\hat{u}_R = v - p_R - xb - t$. On the other hand, after getting complete product information from the physical store, the consumer can then purchase online, i.e. free riding behavior. The utility of a free rider is $\hat{u}_I = v - p_I - (d-x)b - h$, where the factor h ($h>t$) contains the physical shopping cost t and searching cost. Following the assumptions in Bernstein et al. (2009), the online searching cost, the value of which is $h-t$, is for searching the definite product in the Internet channel after supplementing product information in the physical store.

Consumers have three purchasing behavior: (i) buying online directly without in-store service (i.e. with incomplete product information); (ii) buying in the physical store (with in-store service and complete information); (iii) free riding (with in-store service and complete information but buy online). Consumers have two steps to make online or offline purchasing decisions. First, the consumer decides whether to get the in-store service or to buy online directly. Let $u_I = \hat{u}_R$, there is

$$x_{RI} = \frac{d}{2} + \frac{mv - t + p_I - p_R}{2b} \quad (1)$$

The consumers at the interval $[0, x_{RI}]$ prefer to get the in-store service while the consumer at $[x_{RI}, d]$ would rather buy online directly. If the consumer visits the physical store, he can get complete product information and then decide to buy in store or online. If $\hat{u}_R = \hat{u}_I$, there is

$$\hat{x}_{RI} = \frac{d}{2} + \frac{h - t + p_I - p_R}{2b} \quad (2)$$

The consumers at the interval $[0, \hat{x}_{RI}]$ would buy in store; the consumers at $[\hat{x}_{RI}, d]$ would buy online, i.e. free riding happens. When $mv - h \le 0$ there is $x_{RI} - \hat{x}_{RI} \le 0$, the consumer's purchasing decision is depicted in "Fig. 1". The free riding problem is trivial because it never happens. All the consumers who visit the physical store will buy in store.

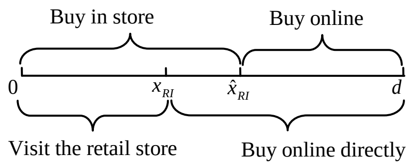

Fig. 1. Consumer's purchasing decision without free riding.

To study on consumers' free riding behavior, it is needed to assume a constraint that

$$mv - h > 0 \text{ (Constraint 1),}$$

such that $x_{RI} - \hat{x}_{RI} > 0$. Consumer's purchase decision is depicted in Fig. 2. There are three segments of consumers: the consumers in the interval $[0, \hat{x}_{RI}]$ visit the physical store and buy in store; the consumers in the interval $[\hat{x}_{RI}, x_{RI}]$ are free riders; the consumers in the interval $[x_{RI}, d]$ buy online directly. Besides, it is necessary to assume $x_{RI} > 0$ and $\hat{x}_{RI} < d$, that is

$$3mv + 3bd + c - s - 2h - t > 0 \text{ and (Constraint 2)}$$

$$3bd - c + s - h + t > 0. \text{ (Constraint 3)}$$

Further, the number of consumers having in-store service (i.e. visitors) is

$$n_R = \frac{N}{d} x_{RI} = \frac{N}{2} + \frac{(mv - t + p_I - p_R)N}{2bd} \quad (3)$$

The number of free riders

$$n = \frac{N}{d}(x_{RI} - \hat{x}_{RI}) = \frac{(mv - h)N}{2bd} \quad (4)$$

The demand in the retail channel

$$D_R = \frac{N}{d}\hat{x}_{RI} = \frac{N}{2} + \frac{(h - t + p_I - p_R)N}{2bd} \quad (5)$$

The demand in the Internet channel

$$D_I = \frac{N}{d}(d - \hat{x}_{RI}) = \frac{N}{2} - \frac{(h - t + p_I - p_R)N}{2bd} \quad (6)$$

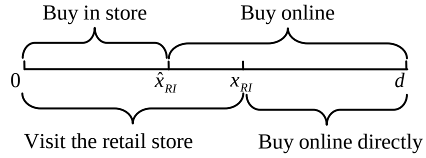

Fig. 2. Consumer's purchasing decision with free riding.

The manufacturer has unit production cost c per product and a fixed cost K in the Internet channel used to develop and maintain the online websites. Therefore, under the constraints (Constraints 1 to 3), the profit functions of the manufacturer and the retailer are respectively

$$\pi_M = (w-c)D_R + (p_I - c)D_I - K \text{ , (7)}$$

$$\pi_R = (p_R - w)D_R - sn_R \text{ (8)}$$

The total profit of the dual-channel supply chain is

$$\pi_T = (p_I - c)D_I + (p_R - c)D_R - sn_R - K \text{ (9)}$$

The manufacturer is the leader in the Stackelberg game and supply chain members optimize profits by prices. From the first-order condition, the optimal prices are

$$p_I^* = \frac{1}{3}(2c + 3bd - h + s + t) \text{ and (10)}$$

$$p_R^* = \frac{1}{3}(c + 3bd + h + 2s - t) \text{ (11)}$$

The optimal prices in Eq. (10) and Eq. (11) provide essential inputs to the agent-based model and the further simulation study.

This research analyzes some key factors' influence on consumers' purchasing behavior based on Eq. (3) to Eq. (6), and gets some managerial implications. (i) When mv is high, the loss of utility due to incomplete product information is high, then consumers would request service eagerly. It is true in the situation that when firms promote innovative products to the market, consumers have to spend more energy to obtain relevant information and experience new products in physical stores. Specially, when consumers have little information of products, they would have high motivation for the in-store service. (ii) After getting complete product information, the consumer's decision to buy online or offline is irrelevant to product valuation and the ex-ante product information. His free riding motivation decreases with the online searching cost. That is, if a consumer can find his definite product online easily, he is more likely to free ride regardless of the product valuation. (iii) Consumers' numbers have reciprocal relations with both the products preference intensity b and product differentiation d. Thus, when b and d is rather small, the two factors influence consumer behavior significantly. It is consistent with the fact that firms usually try the best to please junior members, who tend to have lower preference intensity, and provide higher preferential benefit for them than that for senior members. (iv) When the price gap between dual channels is high, the offline channel's profit decreases, but the online channel's profit increases. The number of free riders is independent of the price gap, but decreases with the degree of product differentiation.

IV. THE SIMULATION STUDY

Section III Basic Model depicts one consumer's purchasing behavior. Further, Section IV considers heterogeneous consumers and studies the consumers' interactions. Specifically, consumers have heterogeneous characteristics and make purchasing decisions not only based on own perceived utilities but also influenced by other consumers, may be their friends, families or others providing useful reviews.

A. The Agent-based Model

Consumers are heterogeneous among product valuations following a truncated normal distribution, which is not uncommon in previous literature (see Feng et al., 2013; Ruiz-Benitez and Muriel, 2014; Pender, 2015). To be specific, the truncated interval is $(0, 2\mu_v)$, and the product valuation of agent i is $v_i \sim N(\mu_v, \sigma_v^2)$, where σ_v^2 reflects consumers' heterogeneous degree. Here it is needed to develop an agent-based model with multiple agents corresponding to heterogeneous consumers. In addition to own pervious utilities, consumers' decisions are influenced by the purchasing information from "neighbors". U^i is used to indicate the previous utilities of agent i and U^{-i} to indicate the average utilities of "neighbors". There is

$$U^{-i} = \frac{\sum_j neighbor_j^{-i} U_j^{-i}}{\sum_j neighbor_j^{-i}} \text{ (12)}$$

where U_j^{-i} is the utilities of agent j and with

$$neighbor_j^{-i} = \begin{cases} 1 & true \\ 0 & false \end{cases} \text{ (13)}$$

Eq. (13) means that if agent j is any one of agent i's neighbors, then $neighbor_j^{-i} = 1$; otherwise $neighbor_j^{-i} = 0$. Thus, the number of agent i's neighbors is $\sum_j neighbor_j^{-i}$. The utility of agent i considering the influence of neighbors is

$$Y^i = (1 - \omega_i)U^i + \omega_i U^{-i} \text{ (14)}$$

where ω_i is a weight. The higher ω_i is, the more agent i's purchasing behavior is influenced by social effects. According to Jiang et al. (2016), an assumption is made that ω_i is normally distributed by $\omega_i \sim N(\mu_\omega, \sigma_\omega^2)$. That is, the social effects on consumers are their characteristics those differ from person to person.

"Fig. 3" depicts the simulation flow of consumer agent i in detail. A multi-replication simulation is conducted and a factor *ticks* is used to count the replications. The simulation system is initialized *ticks*=0, then *ticks*=*ticks*+1 after each one replication of simulation. The simulation stops after consumer agent i makes his purchasing decision: (i) buying online directly (the online demand $D_I = D_I + 1$); (ii) buying in store (the number of visitors $n_R = n_R + 1$ and the offline demand $D_R = D_R + 1$); (iii) free riding ($n_R = n_R + 1$, the number of free riders $n = n + 1$ and $D_I = D_I + 1$); or (iv) give up purchase.

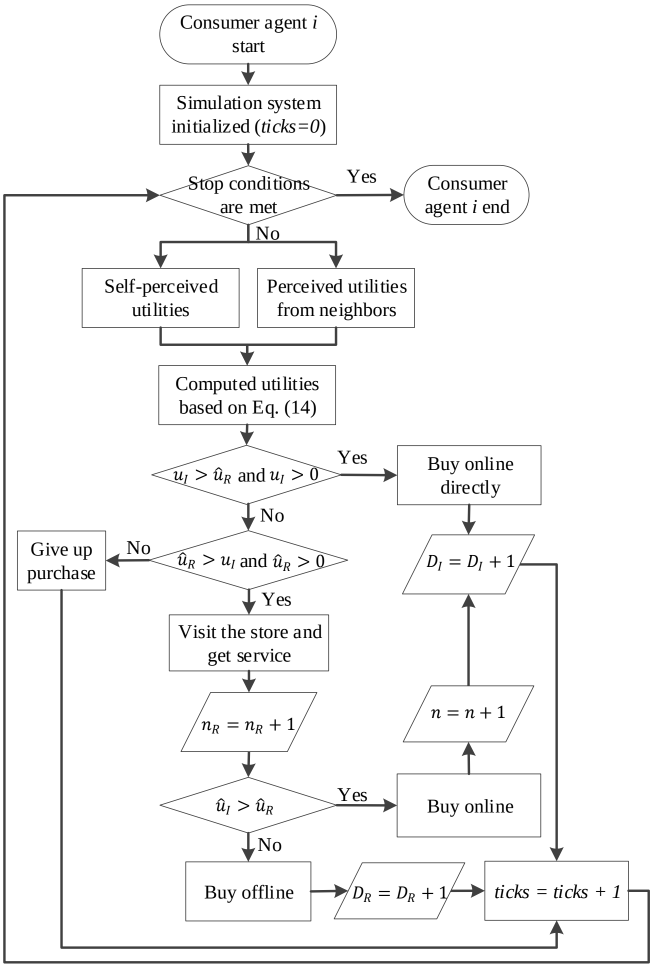

Fig. 3. Consumer agent 's simulation flow.

B. The Simulation Setting

The simulation and experiments are implemented by NetLogo 5.0. Fig. 4 shows the interface of the simulation system and default values. Same as Stummer et al. (2015) and Jiang et al. (2016), the simulation performed 50 replications for each scenario. "Table II" summarizes the main parameter settings. The values of parameters are set based on the assumptions shown in "Table II". All the experiments are conducted in the same simulation system and get the online demand, the offline demand, the numbers of visitors and the number of free riders from the simulation. Simulation results show some management implication.

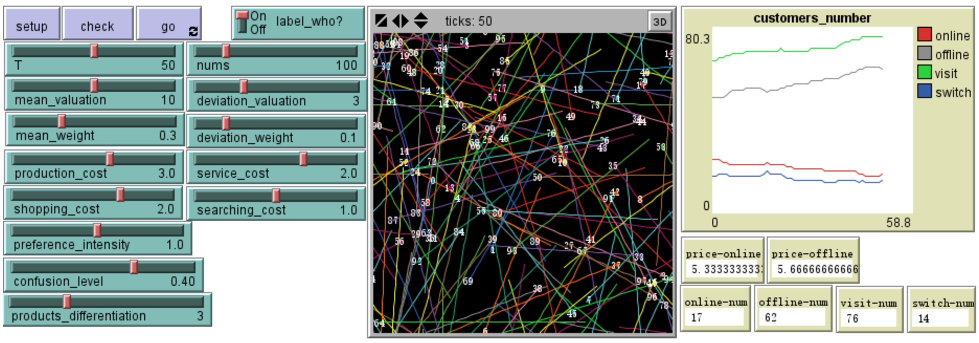

Fig. 4. The interface of simulation system.

TABLE II. THE PARAMETER SETTINGS

Parameter	Value	Assumption
Number of consumers (agents)	100	
Distribution of consumers' product valuations	$N(10,3)$	Constraints 1 and 2, and $\mu_v > p_R^* \geq p_I^*$ from Eq. (10) and Eq. (11).
Distribution of consumers' social effects	$N(0.3,0.1)$	Based on the study of Gardete (2015).
m	0.35; 0.40; 0.45	Constraints1 and 2, and $0 < m < 1$.
d	3; 4; 5	Constraints 2 and 3.
b	1.0; 1.5; 2.0	Constraints 2 and 3.
t	2.0	Constraints 2 and 3.
h	3.0	Constraints 1 to 3, and $h > t$.
s	2.0; 2.2; 2.4	Constraints 2 and 3.

C. Experiment Results and Sensitivity Analyses

Experiments are conducted to explore the key factors those affect consumers' purchase decisions significantly. Besides, comparisons between the simulation results with the theoretical model's findings indicate some new management implications.

1) Consumers' ex-ante product information: Without the in-store service, consumers have incomplete information of products. To test the impact of m on consumers' purchasing behavior, three values of m are considered based on Constraints 1 and 2 and *0<m<1*, as shown in "Table II". Further, sensitivity analyses by IBM SPSS Statistics 22.0 are conducted.

ANOVA at a 95% confidence level indicates some management implications. When *p-value<0.05*, there is significant difference between the tested populations. In contrast, there is no significant difference when *p-value≥0.05*. As it cannot guarantee that the experiment results are normally distributed, a non-parametric method, Kruskal-Wallis H, is also employed to test whether samples are originated from the same population. Samples are divided into groups randomly and conclude there is no significant difference in population distributions with *p-value>0.05*. Finally, "Table III" shows the simulation results under different values of consumers' ex-ante product information.

TABLE III. TEST RESULTS UNDER DIFFERENT CONSUMERS' EX-ANTE PRODUCT INFORMATION (AT A 95% CONFIDENCE LEVEL)

Number	*m*	Mean (SD)	P-value of ANOVA	P-value of homogeneity test	P-value of nonparametric tests
Online demand	0.35	22.48 (1.16479)	.286	.000	.138
	0.40	22.06 (1.92099)			
	0.45	22.36 (.72168)			
Offline demand	0.35	34.58 (1.32619)	.220	.000	.470
	0.40	34.82 (.74751)			
	0.45	34.98 (1.28556)			
Number of visitors	0.35	49.36 (1.94580)	.000	.004	.000
	0.40	51.56 (1.31180)			
	0.45	56.16 (1.11319)			
Number of free riders	0.35	11.78 (1.23371)	.000	.000	.000
	0.40	16.74 (1.50929)			
	0.45	21.18 (.59556)			

Because of a P-value of .138 (>0.05) from the Kruskal-Wallis H test, there is no significant difference among the online demand with different values of *m*. Hence, consumers' ex-ante product information has no significant influence on the online demand. The results of the impact on offline demand are similar. These are consistent with the theoretical model's results.

It is needed to analyze the impact on the number of visitors. The P-value from ANOVA mean test is .000, which indicates that the Means among the three values of m are significantly different, that are respectively 49.36, 51.56 and 56.16. Correspondingly, the standard deviations are 1.94580, 1.31180 and 1.11319. The homogeneity test results in a P-value of .004 (<0.05), indicating that variances are different among the three samples. Due to a P-value of .000 from the Kruskal-Wallis H test, the numbers of visitors are different when the value of m differs. The Mean increases with m. That is, when consumers have enough information about products (e.g. daily necessaries), they tend to buy online directly instead of visiting the physical store. On the contrast, visiting is necessary when products are innovative, new high-tech or needed to be experienced, like perfume and apparel.

It is also necessary to examine the impact on the number of free riders, and find that, when consumers have more ex-ante product information (i.e. low m), they are more likely to buy online after in-store service.

"Table IV" further shows the impact of consumers' ex-ante product information on supply chain members' optimal prices and profits.

TABLE IV. PRICES AND PROFITS UNDER DIFFERENT CONSUMERS' EX-ANTE PRODUCT INFORMATION

m	Online Price	Offline Price	Total Profit
0.35	5.3333	5.6667	40.9467
0.40	5.3333	5.6667	36.2067
0.45	5.3333	5.6667	28.1333

"Table IV" shows that, the total profit of the whole supply chain decreases with m. That is, if consumers have more ex-ante product information (i.e. low m), the total profit is improved. Therefore, firms should take some actions (e.g. advertising) to spread product information in the market and promote consumers' familiarity of products.

2) Unit in-store service cost: Supply chain members decide prices to optimize own profit. "Table II" shows three values of unit service cost (i.e. s) based on Constraints 2 and 3. Table V displays the test results at a 95% confidence level and Table VI indicates the prices and supply chain's profit with different values of s.

TABLE V. TEST RESULTS UNDER DIFFERENT UNIT SERVICE COST (AT A 95% CONFIDENCE LEVEL)

Number	s	Mean (SD)	P-value of ANOVA	P-value of homogeneity test	P-value of nonparametric tests
Online demand	2.0	12.28 (1.05056)	.000	.001	.008
	2.2	12.74 (.94351)			
	2.4	13.18 (1.28873)			
Offline demand	2.0	49.18 (1.75767)	.000	.093	.000
	2.2	48.44 (1.26427)			
	2.4	45.62 (1.35360)			
Number of visitors	2.0	58.24 (1.81333)	.000	.147	.000
	2.2	57.16 (1.26749)			
	2.4	54.50 (1.35902)			
Number of free riders	2.0	9.06 (.58589)	.055	.000	.055
	2.2	8.80 (.67006)			
	2.4	8.88 (.32826)			

TABLE VI. PRICES AND PROFIT UNDER DIFFERENT UNIT SERVICE COST

s	Online Price	Offline Price	Price Gap	Total Profit
2.0	5.3333	5.6667	0.3334	38.3200
2.2	5.4000	5.8000	0.4000	35.4560
2.4	5.4667	5.9333	0.4666	30.5293

"Table V" shows that *p-value<0.05* from the Kruskal-Wallis H test, so unit service cost significantly affects the online and offline demand and the number of visitors, but do not influence the number of free riders. Besides, due to the results of Means, unit service cost has positive effect on the online demand but negative effect on the offline demand.

As shown in "Table VI", the price gap increases with unit service cost, but the whole supply chain's profit decreases with it. Therefore, firms should take action to reduce the in-store service cost and set the same price of the products in dual channels, to improve profit.

3) Product differentiation in dual channels: It is necessary to analyze the effect of product differentiation strategy on consumers' purchasing behavior. At a 95% confidence level, "Table VII" shows the test results. Besides, the impact on prices and profit is depicted in "Table VIII".

"Table VII" shows that all the tests of product differentiation on consumers' numbers result in P-value of .000, indicating that product differentiation has a significant influence on the number of consumers. Besides, Means' results indicate that the online and offline demands, and the numbers of visitors and free riders all decrease with product differentiation. The reason is that when the products in dual channels are highly differentiated, the value of in-store service decreases; as a result, the numbers of visitors and free riders fall. Further, the online and offline demands decrease. Those are consistent with the theoretical results that product differentiation strategy harms the dual channels' demands. However, "Table VIII" indicates that the total profit is improved. This result is similar to the findings of Carlton and Chevalier (2001) that firms benefit from a high level of product differentiation in dual channels.

TABLE VII. TEST RESULTS UNDER DIFFERENT PRODUCT DIFFERENTIATION (AT A 95% CONFIDENCE LEVEL)

Number	d	Mean (SD)	P-value of ANOVA	P-value of homogeneity test	P-value of nonparametric tests
Online demand	3.0	25.86 (1.45700)	.000	.620	.000
	4.0	9.82 (1.38048)			
	5.0	4.76 (1.27071)			
Offline demand	3.0	49.24 (3.57177)	.000	.000	.000
	4.0	27.72 (1.55235)			
	5.0	21.28 (2.24099)			
Number of visitors	3.0	69.80 (3.75798)	.000	.000	.000
	4.0	36.22 (2.42681)			
	5.0	26.04 (3.26990)			
Number of free riders	3.0	20.56 (1.03332)	.000	.076	.000
	4.0	8.50 (1.01519)			
	5.0	4.76 (1.27071)			

TABLE VIII. PRICES AND PROFIT UNDER DIFFERENT PRODUCT DIFFERENTIATION

d	Online Price	Offline Price	Total Profit
3.0	5.3333	5.6667	47.0467
4.0	6.3333	6.6667	56.9333
5.0	7.3333	7.6667	62.8533

V. CONCLUSION

The rapid growth of Internet commerce suggests that the dual-channel structure becomes firms' tendency of development. This paper focuses on firms' product differentiation strategy in a dual-channel supply chain faced with free riders, who take advantage of both the in-store service and the online purchase. The main findings are stated as follows. When consumers have little ex-ante product information, they would consume the in-store service; then they decide to buy online or offline depending on the online searching cost instead of the product valuation. Besides, when the price gap is high, consumers prefer the online channel, but their free riding behavior is independent of the price gap. Further, through multi-agent simulation and sensitivity analyses, this paper suggests that the firm should reduce the cost of in-store service, improve consumers' familiarity about products and differentiate products in dual channels, which would weaken free riding behavior and improve firms' profit. However, this paper only considers a dual-channel monopoly in the market. In the further work, one can extend the model setting is to consider competitions between firms and brands, and carry out studies on market sharing problems.

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