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Research Article

Impact of Heterogeneous Consumers on Pricing Decisions under Dual-Channel Competition

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This paper studies impact of heterogeneous consumer behavior on optimal pricing decisions under dual channel supply chain competition, which consists of one manufacturer and one retailer. The manufacturer is market leader with two sales channels: one is direct channel facing consumers directly and the other is indirect channel facing the retailer. Consumers decide whether to buy and from which channel to buy products. Purchasing decisions are based on considerations of prices posted on different channels, preference or loyalty to specific channels, and degree of rationality in decision-making process. Due to the complexity of heterogeneous consumer decision behavior, traditional mathematical analysis to the pricing problem becomes quite challenging. An agent-based modeling and simulation approach is then proposed and implemented. Simulation results reveal that consumer behavior influences both prices and profits. When consumers are increasingly loyal to the retailing channel, the retailer can make a higher selling price and more benefits. On the other hand, when consumers are increasingly loyal to the direct channel, the number of purchases from the direct channel increases and the manufacturer is better off. It is also interesting to note that as rationality level increases, selling prices for both channels slightly decrease.

1. Introduction

With rapid growth of e-commerce manufacturers have seen online channel as an addition to the existing retailers with brick-and-stone stores, which on one side can reduce their operating costs and, on the other side, can potentially increase market coverage and further enhance interactions with ending consumers. Retailers, however, being aware of the competition of the direct sales channel(s), start to complain about those “stolen sales” to the manufacturers. Such scenario is often called “channel conflict.” From consumers’ perspective, they are more than happy to welcome such dual channel competition, so as to expect lower prices and better service flexibility.

Under dual channel competition, consumers now make their purchasing decisions in a sophisticated manner. First they need to decide whether to buy and then decide from which channel to buy products. Quite a few factors influence their decisions: prices posted in different channels, preference or loyalty to specific channels, degree of rationality in decision-making process, and so forth. Our research interest focuses on the following. What are the impacts of those factors on consumer choice? How the manufacturer and the retailer make their selling prices under dual channel competition? Will the retailer and the manufacturer always be better off if considering consumer behavior?

In specific, we consider impacts of consumer loyalty and bounded rationality on consumers’ decision. Brand loyalty means that people will purchase company A’s products or services even if company B’s products or services are cheaper and/or of a higher quality, if they have brand loyalty to company A [1]. Similarly, we extend brand loyalty definition to channel loyalty, based on observations that aged people prefer to purchasing from brick-and-stone stores instead of e-platforms while young people do on the contrary. Partial rationality or irrationality in the other part of their actions is called bounded rationality [2]. People with bounded rationality fail to find an optimal choice maybe because they lack the ability and resources to arrive at the optimal solution.

This paper considers a dual channel supply chain consisting of one manufacturer and one retailer. Manufacturer is the market leader and makes his pricing decisions for both direct-sales channel and indirect channel. Retailer is the follower and then decides her retailing price accordingly. Existing work has revealed that to deal with channel conflict, manufacturer needs to carefully make pricing decisions for different channels. However, with channel loyalty and bounded rationality behavior considered, a simple numerical example indicates that the concavity (unimodality) of manufacturer's profit is lost (see Figure 3), which becomes a challenge to traditional mathematical modeling approach.

Facing the intrinsic complexity of the optimization problem, this paper proposes an agent-based simulation approach to handle it. Agents are modeled to simulate heterogeneous consumers' decision-making process as well as decision-making of the manufacturer and the retailer. Individual consumer's behavior is described as an intelligent agent's interaction and reaction to its environment. Two reasons support our selection. One is that multiagent model provides a natural description of the system. In the model, the manufacturer is represented as an agent who set the wholesale price and online price; the retailer agent publishes its retail price; and each potential consumer agent individually assesses the market situation and makes purchase decision. The other reason comes from that agent behavior is heterogeneous and nonlinear, which matches the description of consumer who differs in valuation and preference of channel selection.

Simulation results reveal that consumer behavior influences both prices and profits. With more consumers loyal to retail channel, the retailer sets a higher price and gains a higher profit. On the other side, when more consumers are loyal to online channel, the number of purchases from online channel increases and the manufacturer benefits from it. It is also interesting to note as rationality level increases, selling prices for both channels slightly decrease.

The remainder of this paper is organized as follows. Section 2 discusses related work. Section 3 describes model of the dual-channel supply chain system. Section 4 proposes an agent-based simulation and optimization algorithm. Section 5 conducts simulation and summarizes finding. Section 6 concludes the whole paper.

2. Related Work

Two streams of work closely relate to our research problem: one is study on dual channel supply chain system and the other is consumer behavior which was studied intensively in marketing field and extended to operations management area recently.

There is growing literature in supply chain management investigating channel conflicts. To name a few, Yan [3] analyzes differentiated branding strategy and profit sharing mechanism when manufacturer adds a direct channel to its existing retailing channel. Hua et al. [4] analyze impacts of delivery lead time and consumer acceptance of a direct channel on the manufacturer's and the retailer's pricing strategies. Chen et al. [5] discuss dual channel management with service competition.

Consumer behavior has been studied intensively in marketing literature and behavioral science, such as consumer loyalty [1], loss aversion [6], long-tail phenomenon [7], and decoy effect [8]. Recently researchers in operations management have started to include the behavior of decision making into operational models and study its impact on the operational and supply chain decisions. Su [9] uses discrete choice model to describe bounded rationality of decision-maker in newsvendor models. The results are verified with experimental observations which are not able to explain with perfect rationality. Wang and Webster [10] use loss aversion to model decision-maker's behavior in a single-period newsvendor problem. Their results show that if shortage cost is not negligible, then a loss-averse newsvendor may order more than a risk-neutral newsvendor. In a similar newsvendor setting, Li [11] analyzes the impacts of reference point in loss-aversion's value function. Assuming that private valuations of consumers are random distribution with heavy tails, Ibragimov and Walden [7] analyze the optimal pricing strategies for the monopolist producer.

Papers mentioned above mostly adopt analytical modeling approach to mathematically find the optimal pricing decisions. However, when complexity of the problem studied is increasing it becomes quite challenging to achieve analytically results. Researchers turn to multiagent simulation to handle supply chain problems. An agent-based approach can effectively model and simulate complicated interactions among players in supply chain systems, for example, decisions making, information sharing, competition and cooperation, and so forth.

Long and Zhang [12] indicate the advantages of agent-based approach in handling system dynamics, uncertainty, and partial information sharing. They propose an integrated framework for agent-based inventory-production-transportation modeling and distributed simulation of supply chains. Hua et al. [13] investigate how bankruptcy occurs and propagates in supply chain networks. They use agent-based approach to model complicating decision-making process such as horizontal competition among retailers, order allocation strategies of retailers, and wholesale price of manufacturers. Liang and Huang [14] model different inventory systems in a supply chain, where agents are coordinated to control inventory and minimize the total cost of supply chain by sharing information and forecasting knowledge. Other work includes T. Zhang and D. Zhang [8], which exhibit the emergent decoy effect phenomenon in the market. Li and Huang [15] study a dual-channel supply chain pricing problem, in which the value the consumer derives from of the product is assumed to be triangular distributed according to different type of product.

However, studies addressing influence of consumer behavior on a dual-channel supply chain are quite few. This is because competition among channels in supply chain system already makes the problem difficult to handle with mathematical modeling approach; it is even challenging

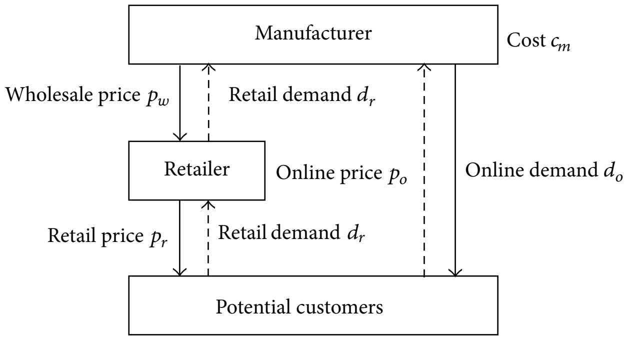


FIGURE 1: The dual-channel supply chain system.

with the consideration of nonlinear function of consumer behavior. This paper contributes to the literature in two aspects. First, we consider heterogeneous consumer behavior in a dual-channel competition supply chain system. Second, we propose an agent-based modeling approach to solve the current problem and obtain inspiring insights.

3. The Dual-Channel Supply Chain Model

We consider a single-period, single product supply chain system under dual channel competition. The supply chain system consists of one manufacturer and one retailer. The manufacturer has a traditional sales channel, that is, an indirect channel facing the brick-and-stone retailer, as well as a new direct channel facing the ending consumer, that is, online channel. This is a very typical dual-channel supply chain setting and has been studied widely in the literature (e.g., [5, 15]).

Figure 1 illustrates the model setting. The manufacturer sells the product to the retailer by the indirect channel at wholesale price p_w and to the ending consumers by direct online channel at price p_o. Unit cost for producing the products is c_m. The retailer also faces the ending consumer and decides retailing price p_r. To avoid the case in which the retailer buy products from the direct channel instead from the manufacturer, we assume $p_w \leqslant p_o$.

Consumer decides whether to buy products or not. If he decides to buy he also needs to choose from which channel to buy: the online channel or the retailer. Denote by d_r the aggregate demand at the retailer channel and d_o the aggregate demand at the online channel. Both the manufacturer and the retailer make their pricing decisions to maximize their own profits.

Consider a Stackelberg game where the manufacturer is the leader and the retailer is the follower. The sequence of events is as follows. Before the selling season, the manufacturer sets the prices of p_w and p_o. The retailer then decides p_r based on the given wholesale price p_w. During the selling season, consumer decides whether or not to buy the product and from which channel to buy it. At the end of the selling season, profits of both the manufacturer and the retailer are calculated. Implicitly we assume there is no capacity constraint of the manufacturer; that is, all orders will be satisfied.

Given the wholesale price p_w offered by the manufacturer, the retailer determines the retailing price p_r so as to maximize her profit, π_r:

$$\pi_r = d_r \cdot (p_r - p_w). \tag{1}$$

Projecting the retailer's best response, the manufacturer needs to carefully determine the pricing decisions so as to maximize his own profit, π_m, which constitutes two parts: net revenue from demand d_r and net revenue from demand d_m:

$$\pi_m = d_r \cdot (p_w - c_m) + d_o \cdot (p_o - c_m). \tag{2}$$

3.1. Consumer Behavior. Facing the multiple sales channels, each consumer needs to decide whether to buy the product and from which channel to buy. This paper considers heterogeneous consumer in the following sense.

First, each consumer has his own valuation of the product, denoting by v_i, with i the index of consumer i, ($i = 1, 2, \ldots, N$). Here N is the market size. We assume that v_i is uniformly distributed from 0 to 1. Normally to say, consumer has willingness to buy the product only if the utility is nonnegative; that is, $u_i \geq 0$. Further denote by $u_{i,r}$ the utility of consumer i if purchasing from retailer channel and $u_{i,o}$ the utility of consumer i if purchasing from online channel.

Second, different consumers have different preferences to the sales channels, to which we refer channel loyalty. Assume that α_r $(0 < \alpha_r < 1)$ proportion of consumers is loyal to the retailer channel, which means that those consumers only purchase from the retailer though the price posted on the direct channel is even less. That is, purchasing occurs when utility $u_{i,r}$ is larger than or equal to 0; that is, $u_i = u_{i,r} = v_i - p_r \geq 0$, while $u_{i,o} = 0$. Similarly α_o $(0 < \alpha_o < 1)$ proportion of consumers is loyal to direct channel, who only purchase from direct channel disregarding the price on the indirect channel; that is, $u_i = u_{i,o} = v_i - p_o \geq 0$, and $u_{i,r} = 0$. The rest $1 - \alpha_r - \alpha_o$ proportion of consumers is so-called "switchers," who are flexible to purchase from either channel.

Among those switchers, consumers might also have different valuations to different channels. Usually, we have $u_{i,r} = v_i - p_r$. However, empirical studies indicate that consumers perceive less utility for products purchased from online channel, often at a discounted value [15]; that is, $u_{i,o} = \theta v_i - p_o$, where $0 < \theta < 1$. The discounted ratio θ is different for varied products. For example, books ($\theta = 0.904$) are more acceptable as compared to food items ($\theta = 0.784$) [15].

Given $u_{i,r}$ and $u_{i,o}$, switcher i then needs to decide which channel to purchase or not. General to say, consumer will select the channel whichever provides the larger utility. Such decision is based on so-called perfect rationality. However, as indicated by [16] consumers make choice decisions with bounded rationality because of lack of information, hassle cost, access to resources, and so forth. Following [16] we assume β $(0 < \beta < 1)$ proportion of consumers is rational, while the rest $(1 - \beta)$ proportion of consumers is bounded rational.

We employ multinomial logit (MNL) choice model to describe channel selection choice under bounded rationality, similar as in [9]. By bounded rationality, we only consider

Table 1: Classification of consumer types.

Consumer type	Loyalty: Indirect channel (α_r)	Loyalty: Direct channel (α_o)	Loyalty: Acceptable to both channels ($1-\alpha_r-\alpha_o$)	Rationality: Perfect rationality (β)	Rationality: Bounded rationality ($1-\beta$)	Fraction to the total population
Type-1	Y*	—*	—	—	—	α_r
Type-2	—	Y	—	—	—	α_o
Type-3	—	—	Y	Y	—	$(1-\alpha_r-\alpha_o)\cdot\beta$
Type-4	—	—	Y	—	Y	$(1-\alpha_r-\alpha_o)\cdot(1-\beta)$

* "Y" denotes "Yes"; "—"denotes "not applicable."

consumers whose utility is positive. That is, if consumers' utility is negative or zero, they are rational enough not to purchase from either channel. Switcher i then chooses channel j with probability φ_{ij}, $j=\{r,o\}$, with

$$\varphi_{ij}=\frac{\exp\left(u_{i,j}\right)}{\exp\left(u_{i,r}\right)+\exp\left(u_{i,o}\right)}. \tag{3}$$

In addition,

$$\varphi_{io}=\frac{\exp\left(\theta v_i-p_o\right)}{\left[\exp\left(\theta v_i-p_o\right)+\exp\left(v_i-p_r\right)\right]}. \tag{4}$$

For each switcher i, $\varphi_{io}+\varphi_{ir}=1$. Based on the description of channel loyalty, channel valuation differences, and levels of rationality, consumers can then be classified into six types, as summarized in Table 1. Figure 2 depicts different decision-making process for these six types of consumers.

3.2. Demand for Different Channels. From Table 1 and Figure 2, we are now able to summarize probability of demand at the retailer side, $\mathrm{Prob}(d_r)$:

$$\begin{aligned}\mathrm{Prob}\left(d_r\right) &= \alpha_r\cdot\mathrm{Prob}\left(v_i\geq p_r\right)+\left(1-\alpha_r-\alpha_o\right)\\ &\quad\cdot\{\beta\cdot[\mathrm{Prob}\left(v_i-p_r\geq 0,\ \theta v_i\geq p_o,\ v_i-p_r>\theta v_i-p_o\right)\\ &\quad+\mathrm{Prob}\left(v_i-p_r\geq 0,\ \theta v_i<p_o\right)]\\ &\quad+(1-\beta)\cdot[\varphi_{ir}\cdot\mathrm{Prob}\left(v_i\geq p_r,\ \theta v_i\geq p_o\right)\\ &\quad+\mathrm{Prob}\left(v_i\geq p_r,\ \theta v_i<p_o\right)]\}.\end{aligned} \tag{5}$$

The first item comes from Type-1 consumers, who are loyal to the retailer channel and purchase from the retailer channel once their valuation is larger than posted price. There are two parts in the second item, with the first one from Type-3 consumers and the second one from Type-4 consumers.

Similarly, probability of demand at the online channel, $\mathrm{Prob}(d_o)$, can be calculated by

$$\begin{aligned}\mathrm{Prob}\left(d_o\right) &= \alpha_o\cdot\mathrm{Prob}\left(v_i\geq p_o\right)+\left(1-\alpha_r-\alpha_o\right)\\ &\quad\cdot\{\beta\,[\mathrm{Prob}\left(v_i-p_r\geq 0,\ \theta v_i\geq p_o,\ \theta v_i-p_o\geq v_i-p_r\right)\\ &\quad+\mathrm{Prob}\left(v_i<p_r,\ \theta v_i\geq p_o\right)]\\ &\quad+(1-\beta)\,[\varphi_{io}\cdot\mathrm{Prob}\left(v_i\geq p_r,\ \theta v_i\geq p_o\right)\\ &\quad+\mathrm{Prob}\left(v_i<p_r,\ \theta v_i\geq p_o\right)]\}.\end{aligned} \tag{6}$$

Probability of no purchase is then

$$\begin{aligned}\mathrm{Prob}\left(\text{no purchase}\right) &= \alpha_r\cdot\mathrm{Prob}\left(v_i<p_r\right)+\alpha_o\cdot\mathrm{Prob}\left(v_i<p_o\right)\\ &\quad+\left(1-\alpha_r-\alpha_o\right)\cdot\mathrm{Prob}\left(v_i<p_r,\ \theta v_i<p_o\right).\end{aligned} \tag{7}$$

3.3. Objective Functions. The retailer's objective is then to find the optimal retailing price p_r to maximize the expected net revenue where $E[\pi_r]=N\cdot\mathrm{Prob}(d_r)\cdot(p_r-p_w)$. Similarly, the manufacturer then needs to decide the optimal p_w and p_o to maximize the expected net revenue, where $E[\pi_m]=N\cdot\mathrm{Prob}(d_r)\cdot(p_w-c_m)+N\cdot\mathrm{Prob}(d_o)\cdot(p_o-c_m)$. To clarify, this paper uses net revenue and profit interchangeably hereafter.

Notice that even for a uniformly distributed valuation v_i, the probability of demands at each sales channel is quite complex due to the heterogeneity of consumer's behavior. This makes the maximization of net revenues of both the retailer and the manufacturer quite challenging in terms of mathematical approach. A simple example illustrates that the net revenues of both manufacturer and retailer are not concave or unimodal in their pricing decisions. This motivates us to consider alternative optimization approach to handle the current problem.

Example 1. Let $p_w=0.2$, $\alpha_r=0.3$, $\alpha_o=0.3$, $\beta=0.6$, $\theta=0.9$. Figure 3(a) plots the net revenue of the retailer with p_r the horizontal axis (given $p_o=0.4$). Figure 3(b) plots the net revenue of the manufacturer with p_o the horizontal axis (given $p_w=0.4$).

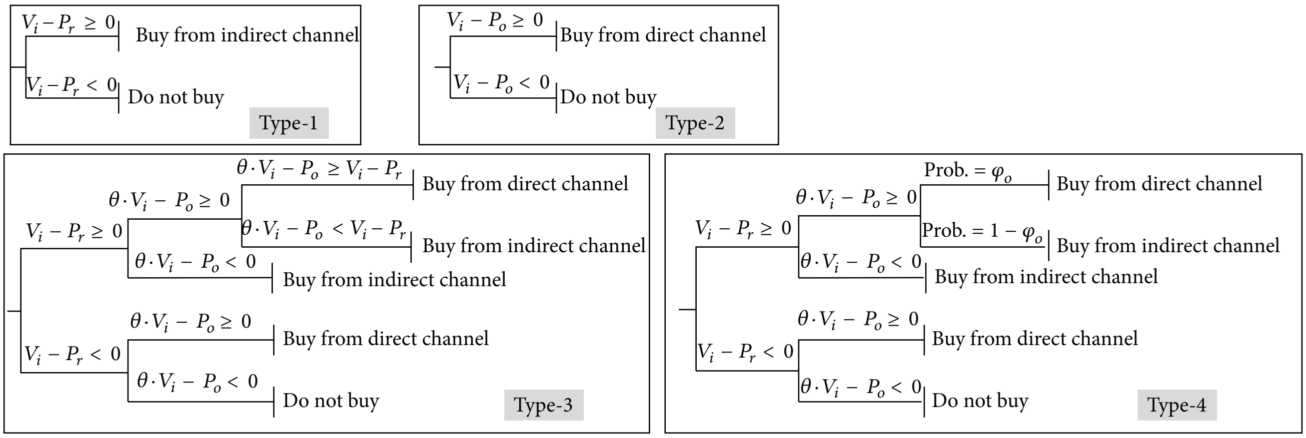


Figure 2: Decision trees for different types of consumers.

4. An Agent-Based Model and Simulation Algorithm

4.1. An Agent-Based Model. Agent-based modeling has been proved to be an effective pragmatic approach to analyze supply chain design and management problems [6]. In the dual-channel supply chain system we establish three types of agents:

(i) manufacturer agent: the manufacturer is modeled as an autonomous agent who sets his wholesale price p_w and online price p_o and calculates his profit based on consumer purchasing behavior;

(ii) retailer agent: the retailer agent is modeled as an autonomous agent who decides her retail price p_r to maximize her revenue;

(iii) consumer agents: consumers are modeled as a collection of N consumer agents. Each consumer agent i, $i \in [1, \ldots, N]$, differs in channel loyalty, channel valuations as well as levels of rationality. Agent i makes his decision of purchase and channel of purchase based on the net utility of $u_{i,r}$ and $u_{i,o}$.

4.2. Simulation Algorithm. Simulation steps for the Stackelberg game are as follows.

(1) The manufacturer agent first announces p_w and p_o, and the retailer agent announces p_r.

(2) Based on the prices posted, channel loyalty, utility preference for different channels, and rationality levels, each consumer agent makes his own purchasing decision.

(3) The manufacturer agent and the retailer agent collect profits from N consumer agents, separately.

Pricing decisions of the manufacturer (retailer) are made based on the best response to the action of the retailer (manufacturer) to maximize his own expected profit, that is, (2) (or (1)). In game theory, the best response is the strategy which produces the most favorable outcome for a player. Such a process is so-called best response dynamics [17] and has been widely used in solving gaming problems in computer-based modeling setting [18]. Pseudocode of the algorithm is developed and proposed in Algorithm 1. We enumerate pricing decisions in their feasible value sets; that is, $p_w \in [0, 1.0)$, $p_o \in [p_w, 1.0)$, $p_r \in [p_w, 1.0)$. Parameter $\varepsilon = 0.005$ is the computing step which determines the precise of the results.

5. Simulation Results and Analysis

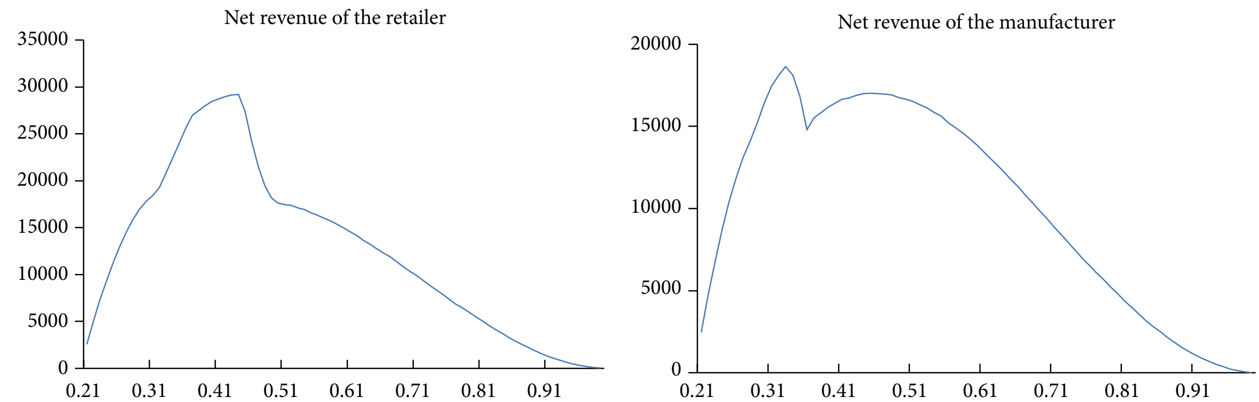
5.1. Verification and Validation. Considering agent-based modeling is "bottom-up" instead of "top-down" which traditional mathematical modeling approach often employs, we need first to verify and validate the established agent model.

To do so, we establish a base scenario. If the simulation results of the base scenario match theoretical results, we then validate the agent model.

Base Scenario. Set market size $N = 10{,}000$ and product cost $c_m = 0.20$. Suppose that all consumers are perfectly rational and they are acceptable to both sales channels. In addition, purchasing from online channels makes no difference from retail channel. That is, $\alpha_r = \alpha_o = 0$, $\beta = 1$, $\theta = 1$. Based on these assumptions theoretical results of optimal prices can be easily achieved.

Figure 4 depicts the simulation results of the optimal net revenue of both the manufacturer and the retailer with respect to the wholesale price p_w. We observe that when $p_w = 0.4$ the manufacturer's net revenue achieves maximum, with $\pi_m = 0.19764$ and $\pi_r = 0.04941$. This is consistent with theoretical results in [15], where $p_o^* = p_w^* = 0.40$, $\pi_m^* = 0.20$, and $\pi_r^* = 0.05$.

Repeat the simulation for 100 times, and we can depict in Figure 5 the Quantile-quantile plot of π_m. It shows that the simulation results of 100 replications ($M = 100$) are normally distributed, which indicates that setting M to 100 is fairly enough.



(a) (b)

Figure 3: (a) Nonconcavity of retailer's net revenue. (b) Nonconcavity of manufacturer's net revenue.

```
FUNCTION StackelbergGame ()
ε = 0.005;
finalPw = finalPr = finalPo = 0.0;
finalπm = finalπr = 0.0;
FOR (P_w = 0.0; P_w < 1.0; P_w +=ε) {
    bestPo = bestPr = P_w;
    bestπm = bestπr = 0.0;
    FOR (P_o = P_w; P_o < 1.0; P_o +=ε) {
        maxπr = maxπm = maxPr = 0.0;
        FOR (P_r = P_w; P_r < 1.0; P_r +=ε) {
            (πm, πr) = simulation (P_w, P_r, P_o);
            IF (maxπr < πr) {
                maxπr = π_r, maxπm = π_m;
                maxPo = P_o;
            }
        }
        IF (bestπm < maxπm) {
            bestπm = maxπm, bestπr = maxπr;
            bestPr = maxPr, bestPo = P_o;
        }
    }
    IF (finalπm < bestπm) {
        finalπm = bestπm, finalπr = bestπr;
        finalPw = P_w, finalPr = bestPr, finalPo = bestPo;
    }
}
RETURN (finalPw, finalPr, finalPo, finalπm, finalπr);
```

Algorithm 1: Pseudocode for the dual-channel Stackelberg game.

5.2. Simulation Results and Analysis. We are now ready to run agent-based simulation to investigate the optimal pricing decisions. We take particular interests in

(1) impact of channel loyalty on demands, pricing decisions, and net revenues;

(2) impact of rationality (bounded rationality) on demands, pricing decisions, and net revenues.

Set market size $N = 500{,}000$, product cost $c_m = 0.20$. We first establish a benchmark case (Scenario A) by setting $\alpha_r = 0.30$, $\alpha_o = 0.30$, $\beta = 0.60$, $\theta = 0.90$. Table 2 shows the optimal solutions. The optimal pricing decisions for the manufacturer is $p_w^* = 0.60$, and $p_o^* \approx p_w^*$. The optimal retailing price is higher. There are about 43.2% consumers that will buy from the direct online channel.

Next, we simulate three special scenarios and report the results in Table 2. Scenario B changes $\beta = 1.00$ while keeping the other parameters unchanged, which means all the consumers in the market are "perfectly rational"—Type-1, Type-2, and Type-3. Scenario C sets $\alpha_r = \alpha_o = 0$, which

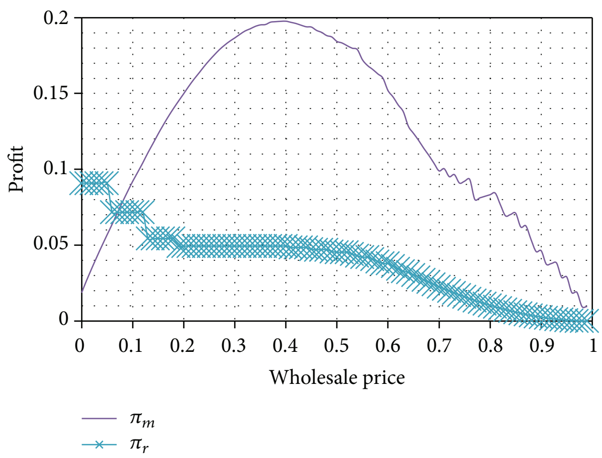


FIGURE 4: Simulation results of the base scenario.

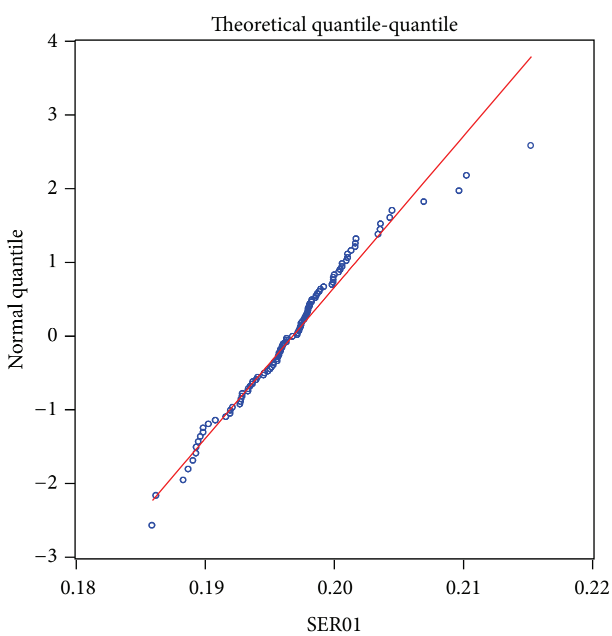


FIGURE 5: Quantile-quantile plot of π_m.

TABLE 2: Optimal solutions under four scenarios.

	p_w	p_o	p_r	d_r	d_o	π_m	π_r
Scenario A	0.60	0.61	0.68	97,461	74,159	69,389.59	7,796.88
Scenario B	0.55	0.55	0.61	136,053	67,692	71,310.75	8,163.18
Scenario C	0.57	0.57	0.63	148,635	36,615	68,542.50	8,918.10
Scenario D	0.57	0.57	0.63	185,197	0	68,522.89	11,111.82

implies all consumers are switchers and no channel loyalty—Type-3 and Type-4. Scenario D further eliminates the impact of bound rationality by setting $\alpha_r = 0.00$, $\alpha_o = 0.00$, $\beta = 1.00$, $\theta = 0.90$, which means only Type-4 consumers in the market.

Comparing results of Scenario B to Scenario A, we find as consumers become more rational, both retailing price and online price decrease while profits of both manufacturer and retailer increase. Comparing Scenario C to Scenario A, we find that when there is no channel loyalty, selling prices for both channels decrease while demand from the retailing channel increases much and the retailer enjoys a higher profit level. Comparing Scenario D to Scenario C, we find that when no behavior pattern exists, the retailer is happy because all consumers approach her for purchasing. Although online price is lower than retailing price, considering the discounted value of online product, consumers still prefer to retail channel. Such scenario is also observed in [13].

We change values of α_r, α_o, and β separately, so as to observe impacts of each parameter. Table 3 summarizes optimal solutions for varying parameters, including optimal pricing decisions, net revenues of the manufacturer, the retailer, and the total supply chain, as well as the number of purchases from each channel.

Based on Table 3, we summarize our observations as follows.

Impact of Channel Loyalty. We observe that the impact of loyalty to retail channel and online channel is quite different. As α_r increases, p_r^* and p_o^* exhibit an increasing trend; however, p_w^* does not show clear pattern. The number of purchases from online channel decreases, while the number of retail channels does not change much. The total number of purchases decreases as well. As a result, the profit of the retailer increases while the profit of the manufacturer decreases. The manufacturer should then adjust their marketing strategy when the ratio of consumers who are loyal to retail channel is large, for example, offering promotion or deeper discounts at online channels, to prevent their profits reduced.

As α_o increases, p_r^*, p_w^*, and p_o^* do not change much. The number of purchases from online channel increases, while purchase from retail channel decreases significantly. This explains the reason why sales at retail channel decrease significantly when consumers get used to online shopping. The manufacturer tends to get benefit from the increasing online sales while the retailer may be harmed. For retailers, they should then increase marketing promotion to drag consumers back to the traditional retailing channel when more consumers get used to online shopping.

Impact of Rationality. Notice that β denotes the degree of rationality. As β increases, p_r^*, p_w^*, and p_o^* turn to be slightly decreasing. As a result, the number of purchasing for both channels increases. When rationality level is low, which means consumers is possible to select the online channel instead of retail channel no matter what the selling price is. The retailer is then less motivated to lower the price to attract consumers. When rationality level is high, the retailer can use pricing decisions to attract consumers to buy from her channel. The same argument goes for the online channel pricing decisions. We further see that the manufacturer benefits from higher rationality level; however, the retailer does not turn to be obvious pattern of increasing or decreasing with respect to the rational level. This is because the retailer's profit comes from the price difference of p_r^* and p_w^* and the number of purchases from the retail channel, with one factor decreasing while the other factor increasing with

Table 3: Optimal solutions for varying parameters.

α_r	$p_w{}^*$	$p_r{}^*$	$p_o{}^*$	$\pi_S{}^*$	$\pi_r{}^*$	$\pi_m{}^*$	#_total[1]	#_Retailer[2]	#_Online[3]
0.2	0.57	0.64	0.57	77780.62	6921.18	70859.44	191512	98874	92638
0.25	0.6	0.67	0.6	77232.76	6749.96	70482.8	176207	96428	79779
0.3	0.6	0.68	0.61	77186.47	7796.88	69389.59	171620	97461	74159
0.35	0.62	0.7	0.63	75598.64	7568.88	68029.76	160409	94611	65798
0.4	0.59	0.69	0.62	76672.47	9823.5	66848.97	166181	98235	67946
0.45	0.58	0.69	0.62	76770.26	11061.82	65708.44	166026	100562	65464
0.5	0.58	0.7	0.63	76089.79	11914.44	64175.35	160790	99287	61503
α_o	$p_w{}^*$	$p_r{}^*$	$p_o{}^*$	$\pi_S{}^*$	$\pi_r{}^*$	$\pi_m{}^*$	#_total	#_Retailer	#_Online
0.2	0.61	0.68	0.61	76234.88	7638.19	68596.69	167309	109117	58192
0.25	0.58	0.66	0.59	77817.58	8568.08	69249.5	180309	107101	73208
0.3	0.6	0.68	0.61	77186.47	7796.88	69389.59	171620	97461	74159
0.35	0.61	0.69	0.62	76608.14	7113.28	69494.86	167581	88916	78665
0.4	0.59	0.68	0.61	77324.73	7606.62	69718.11	174167	84518	89649
0.45	0.58	0.68	0.61	77846.11	7824.3	70021.81	176510	78243	98267
0.5	0.6	0.7	0.63	76783.22	6889.6	69893.62	167350	68896	98454
β	$p_w{}^*$	$p_r{}^*$	$p_o{}^*$	$\pi_S{}^*$	$\pi_r{}^*$	$\pi_m{}^*$	#_total	#_Retailer	#_Online
0.6	0.6	0.68	0.61	77186.47	7796.88	69389.59	171620	97461	74159
0.65	0.58	0.66	0.59	77584.35	8141.52	69442.83	180668	101769	78899
0.7	0.61	0.68	0.61	77269.64	6997.69	70271.95	171395	99967	71428
0.75	0.59	0.66	0.59	77962.76	7328.3	70634.46	181114	104690	76424
0.8	0.58	0.65	0.58	78466.33	7556.43	70909.9	186605	107949	78656
0.85	0.57	0.64	0.57	78652.51	7745.71	70906.8	191640	110653	80987
0.9	0.57	0.64	0.57	78730.87	7798.91	70931.96	191708	111413	80295

[1]"#_total" means total number of purchases.
[2]"#_Retailer" means number of purchases from retailer channel.
[3]"#_Online" means number of purchases from online channel.

rationality level. However, the manufacturer can benefit by adding an online channel, considering the total number of purchases is increased much more than the slightly decrease of online selling price and wholesale price.

As indicated in above discussion, in a Stackelberg game, the manufacturer as a dominant takes advantage by introducing online channel to increase his profit. On the contrary, the retailer could get benefit from cultivating consumer loyalty to the retail channel.

6. Conclusions

This paper addresses impact of consumer behavior on pricing decisions under dual-channel competition. Consumers are heterogeneous and each of them makes his own purchasing decision according to prices posted on both channels, channel loyalty, utility preference for different channels, and degree of rationality in decision-making process. Results of agent-based simulation show that consumer behavior influences both prices and profits. With more consumers loyal to retail channel, the retailer set a higher price and gains a higher profit. On the other side, when more consumer loyal to online channel, the number of purchases from online channel increases and the manufacturer benefits from it. It is also interesting to note as rationality level increases, selling prices for both channels slightly decrease.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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