# Advance Selling in the Presence of Product Diffusion Effect and Strategic Consumers

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**ABSTRACT**

Ordering and pricing are the most critical aspects of an e-commerce retailer's operations. Retailers' pricing decisions affect the demand of potential consumers in the marketplace, while appropriate order quantity decisions can help companies optimize their supply chain and logistics management, thereby improving their profitability. Based on the pre-sale background in the e-commerce industry, this paper considers consumer strategic behaviour and the product diffusion effect. Moreover, the theory related to expected utility and differential equation is used to design and solve a two-stage sales model of retailer expected revenue gives the optimal pre-sale pricing and order quantity considering linear diffusion effect and convex product diffusion effect. This paper guides e-commerce retailers to make pre-sale pricing and ordering strategies and has implications for them.

***Keywords:*** *inventory management; pricing decision; advance selling; the product diffusion effect; interface on marketing and operations management*

## 1. Introduction

With the rapid development of Internet technology, online advance selling has become an economical and efficient marketing strategy in many industries. Retailers can showcase new brand products through advance selling, and consumers can preview and order products online, which helps retailers grasp the market demand and consumers' willingness to buy and arrange orders through presale information to alleviate the problem of inventory backlog. Generally speaking, advance selling includes discount and premium presale. In practice, most retailers adopt the strategy of the discounted presale. Consumers who buy during the presale period have price concessions and avoid the risk of possible stock-outs. However, customers also face the risk of their valuation being lower than the price paid due to the greater uncertainty of product valuation during the presale period. The strategic behaviour of consumers is ubiquitous in practice. Strategic consumers will integrate information from various channels and consider factors such as the product price and availability during the regular period. Weigh the effectiveness of the presale period and the regular period, and make purchases when their interests are maximized.

Product diffusion is the process by which consumers continuously accept a new product over time after it is launched. In recent years, major social platforms have become shopping and sharing platforms for consumers to "plant grass" and "pull grass". The wide application of personalized recommendation technology also makes it easier for customers to obtain detailed evaluation information of products of interest, and the communication between consumer groups will affect the purchase decision of potential consumers. Communication between groups of consumers can influence the purchasing decisions of potential consumers [19]. The impact of consumer interactions on product diffusion has led to a dynamic correlation between retailers' demand in two periods. The demand for products at a later period depends on the consumers' purchase behaviour in the first period [2].

When considering both the prevailing consumer behaviour and the product diffusion effect, what kind of presale pricing should retailers adapt to increase profits throughout the sales period. Few pieces of literature on the presale strategy consider the product diffusion effect. Therefore, this paper will study the formulation of the presale strategy considering the consumer strategic behaviour and the product diffusion effect through establishing and analyzing the theoretical model.


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## 2. Literature Review

The literature relevant to this paper is in one category on strategic consumers and another on product diffusion effects. Firstly, there has been a wealth of literature on strategic consumers. Su [17] was the first to introduce strategic consumer behaviour into the Newsboy model, examining the optimal pricing and order amount in rational expectations equilibrium. Yossi [25] showed that ignoring strategic consumer behaviour can result in lost revenue. More researchers have introduced consumer strategic behaviour into retailer decision-making. Swinney [6] investigated the choice of strategic consumers between the presale and regular periods. Li [11] found that the implementation of presale strategies facilitated retailers' price discrimination and order amount, and suggested that offering price guarantees is an effective way to attract strategic consumers. Zhao [28] uses risk preference as a criterion to classify consumers into two types: loss aversion and risk preference, and explores the impact of consumer composition on firms' presale strategies. Tang and Lim [12] investigate presale pricing mechanisms that include short-sighted consumers, strategic consumers, and monopolistic merchants when speculators are involved. Wang studied retailers' presale and return strategies considering strategic consumers' loss aversion. Wang [20] found that retailers have to set a lower presale price due to strategic consumers' loss aversion and that implementing a return strategy could lead to better returns for retailers. Lin [13] discussed the impact of retailers' presale discounts and volumes on their revenue based on consumers' strategic behaviour and network externalities. Dana [8] argued that strategic consumer demand for presale products depends on price and inventory. Xie [18] analyzed strategic consumer behaviour when there are capacity constraints in the presale process, arguing that buying in advance can reduce the consumer the risk of out-of-stocks and increase retailers' profits. Yin [24] examines the optimal purchase decision of strategic consumers and the optimal pricing decision of retailers under a deposit-added presale strategy. Prasad and Zhao [15] studied presale strategies that consider random market demand and uncertain consumer valuations. Presale strategies mentions above considering strategic consumers have not been studied in combination with product diffusion effects.

The second related literature is the research on the product diffusion effect. Bass and Rogers [2] proposed the important behavioural hypothesis that consumers' product purchase decisions will be influenced by consumers who have already purchased the product and referred to this as the diffusion effect. As the e-commerce industry grows, it makes it easier for potential consumers to access reviews of products from previous consumers, influencing their attitudes towards the product [9]. Secondly, early sales can increase product awareness [1]. Ho [10] believes that the value of a customer of the company to the business includes not only the purchase value of the customer but also the value of the consumer's influence on others. Smith argues that consumers' use of social networks to communicate product information influences their decisions [19]. Both positive and negative word-of-mouth about a product on e-commerce platforms or forums can influence consumers' purchase decisions [14], with negative word-of-mouth having a greater impact than positive word-of-mouth [7]. Bottomley suggests that price influences potential market demand [5]. The existing literature on product diffusion is also based on market forecasts and simulations of the product diffusion process. For example, in the case of new product diffusion, Moe [22] model the diffusion of new products concerning presale periods. Alain[4] constructs a generic mathematical model of the diffusion of an innovative product in a given market, which is used to analyze and forecast product demand. Gu [9] finds macroscopic patterns of new product diffusion by modeling consumer interaction behaviour during product diffusion and exploring the influence of factors such as product utility parameters and group communication on macroscopic diffusion outcomes. Zhao [26] analyzed the impact of consumer interaction on product diffusion rate from the perspective of network effects based on the product life cycle perspective using micro diffusion models. Very few scholars have studied ad selling strategies based on product diffusion effects. Xu [23] studied the premium presale strategy of short-life-cycle products and discussed the influence of two different demand diffusion effect models, linear diffusion effect and convex diffusion effect, on the order amount. However, the research on consumers strategic behaviour was insufficient. Zhao [27] constructs a premium presale decision model based on prospect theory and product diffusion effects.

Few literature have studied retailer's pricing and inventory strategies considering strategic consumers and product diffusion effect. Therefore, this paper considers the two stages of the presale period and the regular period, and analyzes the influence of consumer strategy behaviour and product diffusion effect on the advance selling strategy. This paper constructs consumer utility and merchant profit expectation function to investigate the optimal presale price and optimal order amount for merchants under the effects of linear product diffusion utility and convex product diffusion, and to analyze the effects of the product diffusion coefficient and the proportion of strategic consumers on presale pricing and order amount.

## 3. Model description and assumptions

Assume that a monopoly retailer sells a product in two phases: the presale period and the regular period. Consumers can order goods during the presale period (Paid but not received), and the retailer promises to meet the customer's preorder demand at the beginning of the

regular period. In this paper, we assume that consumers are heterogeneous and classify them into informed and uninformed consumers according to whether they are aware of the presale. Informed consumers will have prior knowledge of the seller's presale and will enter the market during the presale period, classifying informed consumers into short-sighted and strategic consumers. The proportion of strategic consumers is $\lambda$ .The proportion of strategic consumers who choose to buy during the presale period or wait is based on maximizing their returns, while short-sighted consumers choose to buy as long as their product valuation is greater than the price, and choose to leave otherwise. Uninformed consumers are unaware of the presale and will only enter the market during the regular sales period, all of whom are short-sighted. There is a product diffusion effect in the market, where product sales in the presale period will influence customers' purchase decisions in the regular period, and hence the demand for the product in the regular sales period. It is assumed that the number of consumers who enter the market during the regular period due to the product diffusion effect is $g(D_1)$ .

The retailer adopts the pricing strategy of price commitment. At the beginning of the presale period, the retailer informs the consumer of the presale price $P_a$ and the price $P$ of the regular period. Assuming that the retailer purchases the product at a unit cost of $c$ . The retailer's selling price in the spot period $P$. Exogenously given, for unsold products, let the residual value be $s$ , and $P > c > s$ , without taking into account the out-of-stock cost of the product. $V^A$ denotes the consumer's valuation of the product during the presale period, and $V$ denotes the consumer's valuation in the regular period, assuming that both obey the probability density function $f_x(\bullet)$ on $[0, v]$ and the uniform distribution of the distribution function $F_x(\bullet)$, $\bar{F}_x(\bullet)$ =1-$F_x(\bullet)$ .The retailer needs to decide the optimal order amount before the spot period. After entering the spot period, retailers cannot make replenishment. $N_a$ denotes the number of informed consumers, $N_a \sim [\mu_1, \sigma_1]$ . $N_w$ denotes the number of uninformed customers who enter the market during the regular period, $N_w \sim [\mu_2, \sigma_2]$.It is assumed that the number of informed consumers and the number of uninformed consumers is uncorrelated. This model aims to maximize the retailer's total profit at both stages, and the decision variables are the retailer's presale price and the order amount.

## 4. Model building and solving

Based on the above description of the consumer's decision, the expected utility of a strategic consumer's purchase in the pre-sale phase is

$$u_1 = V^A - P_a$$

The expected utility of choosing to wait until the regular sales period to purchase is

$$u_2 = k\left(\int_P^v (V-P) f_x(V) dV\right) = \frac{k(v-P)^2}{2v}$$

When the expected utility of a consumer's purchase during the presale period is greater than the expected utility of waiting until the regular period to purchase, i.e. $u_1 \geq u_2$ when the strategic consumer chooses to purchase the product during the pre-sale period.

When $V^{A*} = P_a + \frac{\xi(v-P)^2}{2v}$ then $u_1 = u_2$ , therefore $P\{u_1 > u_2\} = \bar{F}(V^{A*})$. To ensure the generalizability of this paper's analysis, this paper assumes $V^{A*} < v$ is equivalent to $P_a < v - \frac{k(v-P)^2}{v^2}$. The demand of strategy consumers during the presale period $D_{1c} = \lambda N_a \bar{F}(V^{A*})$ .the demand of short-sighted consumers during the pre-sale period is $D_{1d} = (1-\lambda) N_a \bar{F}(P_a)$, the number of strategic consumers who wait until the regular period before deciding whether to purchase is $D_{2c} = \lambda N_a F(V^{A*})$. The demand for the product during the presale period is $D_1 = D_{1c} + D_{1d}$. The number of customers who buy products during the regular period subject to presale information, is $g(D_1)$ Therefore, the demand for the product during the regular period is

$$D_2 = [N_W + g(D_1) + D_{2c}]\bar{F}(P) + g(D_1)$$

$\Pi$ is the expected profit of the retailer in two stages, then

$$\Pi = maxE\left\{(P_a - c)D_1 + (P-s)Emin(D_2, Q) - (c-s)Q\right\}$$

This is a Newsboy model. From the study in the literature (Silver 1998), it is clear that the optimal two-stage order amount for a given presale price is

$$D^* = \mu_1[\lambda F(V^{A*}) + (1-\lambda)\bar{F}(P_a)] + [\mu_2 + z\sigma_2]\bar{F}(P)$$
$$+ g(D_1) + \lambda N_a F(V^{A*})\bar{F}(P)$$

Where $z = \Phi^{-1}\left(\frac{P-c}{P-s}\right)$; $\Phi$ is the distribution function of standard normal distribution. The total expected profit is

$$\Pi^* = E((P_a - c)D_1) + E((P-s)D_2) - (P-s)z_2$$

### *4.1 Linear product diffusion effect*

The Assumptions $g(D_1)$ is the number of customers entering the market due to sales in the presale period during the regular period and let $g(D_1)$ be a monotonic function of $D_1$ a monotonic function of $g(D_1) = \beta D_1$, where $\beta$ denotes the extent to which product diffusion utility affects demand in the regular period, when $\beta > 0$ indicates a positive product diffusion effect, i.e. the greater sales in the presale period, the more consumers will make purchases in the regular sales period. When $\beta < 0$, it indicates a negative product diffusion effect. The more sales in the presale period, the less

customer demand in the market. Based on above the following conclusions can be drawn.

The optimal presale price for retailers is

$$P_a^* = \frac{(P-c)(\lambda-\beta)+c+v}{2} - \frac{2P\lambda(P-c)+k\lambda(P-v)^2}{4v}$$

**Lemma 1.** Under certain conditions, there is a unique optimal presale price, and the optimal presale price is a decreasing function of $\beta$, that is, it decreases with the increase of the positive product diffusion effect, and with the increase of the negative product diffusion effect and decrease. There is no interaction between the proportion of strategic consumers and the product diffusion effect on the retailer's optimal pre-sale pricing decision.

When$P_a < \frac{v^2-k(v-P)^2}{2v}$, let $\frac{\partial \Pi^*}{\partial P_a} = 0$ get $P_a^*$, and $\frac{\partial^2 \Pi^*}{\partial^2 P_a} = -\frac{4\mu_1}{v} < 0$, Therefore when the presale price is $P_a^*$, the maximum value $\Pi^*$. Taking the partial derivative of $P_a^*$, $\frac{\partial P_a^*}{\partial \beta} = -\frac{(P-c)}{2} < 0$ .Therefore, It can be seen that the optimal pre-sale pricing is a decreasing function of the product diffusion effect coefficient $\beta_1$.

**Lemma 2.** When the product availability in the regular period $k$ is below a certain threshold, the optimal presale pricing increases as the proportion of strategic consumers $\lambda$ . Conversely, optimal presale pricing decreases as the proportion of strategic consumers increases.

$$\frac{\partial P_a^*}{\partial \lambda} = \frac{2(v-P)(P-c)-k(v-P)^2}{4v}$$

let$\frac{\partial P_a^*}{\partial \lambda} = 0$ when $k^0 = \frac{2(P-c)}{v-P}$,also$\frac{\partial P_a^*}{\partial \lambda \partial k} = -\frac{(v-P)^2}{4v} < 0$ , so that when $k < k^0$ , $\frac{\partial P_a^*}{\partial \lambda} > 0$, otherwise, $\frac{\partial P_a^*}{\partial \lambda} \leq 0$,When the presale price is $P_a^*$, the retailer's optimal ordering decision is

$$D^* = (1+\beta)\mu_1 + \mu_2 + z\sigma_2 - \frac{P(\mu_2+z\sigma_2)+P_a\mu_1(\beta+1-\lambda)}{v} - \frac{PP_a\mu_1\lambda}{v^2} - \frac{k\mu_1\lambda(P+\beta k)(P-v)^2}{2v^3}$$

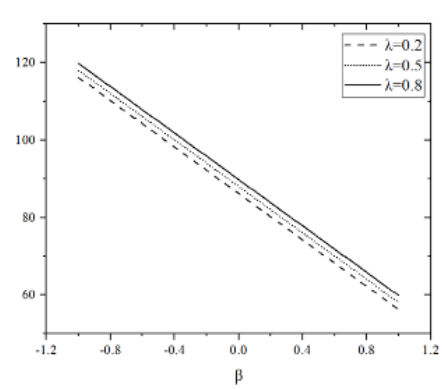
**Lemma 3.** There is an interaction between the proportion of strategic consumers and the product diffusion effect on the retailer's optimal order amount decision. When $\lambda \leq \lambda^0$ , the retailer's optimal order amount is an increasing function of the product diffusion effect coefficient, and conversely the optimal order amount is a decreasing function of the product diffusion coefficient. When $\beta \leq \beta^0$, the retailer's optimal order amount is an increasing function of the proportion of strategic consumers, and the optimal order amount is a decreasing function of the proportion of strategic consumers.

$$\frac{\partial D^*}{\partial \beta} = \frac{\mu_1\left[2v(v-P_a)-k\lambda(P-v)^2\right]}{v^2}$$

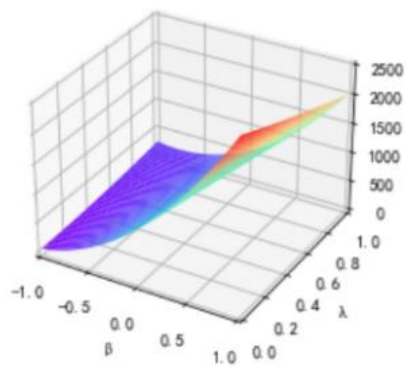
$$\frac{\partial D^*}{\partial \lambda} = \frac{\mu_1\left[2v(v-P_a)-k\lambda(P-v)^2\right]}{v^2}$$

Let $\frac{\partial D}{\partial \beta} = 0$ get $\lambda^0 = \frac{2v(v-P_a)}{k(P-v)^2}$. Let $\frac{\partial D}{\partial \lambda} = 0$ get $\beta^0 = \frac{2vP_a-kP(v-P)}{kv(v-P)}$ . $\frac{\partial^2 D^*}{\partial \beta \partial \lambda} = -\frac{2k\mu_1(v-P)^2}{v^2} < 0$ , when $\lambda < \lambda^0$ , $\frac{\partial D}{\partial \beta} > 0$, otherwise, $\frac{\partial D}{\partial \beta} \leq 0$ . When $\beta < \beta^0$ , $\frac{\partial D}{\partial \lambda} > 0$, otherwise, $\frac{\partial D}{\partial \lambda} \leq 0$.

The analysis shows that when the positive product diffusion effect is greater, the retailer will set lower the presale price to attract more consumers to buy during the presale period to stimulate greater market demand during the regular period, thus maximizing the total market demand in both periods. When the negative product diffusion effect is greater, the retailer will set a higher presale price to increase the marginal profit of the product and reduce the demand in the presale period to reduce the impact of the negative diffusion effect on sales in the regular period. In the case of moderate product availability during the regular period, retailers will attract strategic consumers to purchase during the regular sales period by increasing the presale price, as it is necessary to set the lower presale price to attract strategic consumers than to attract short-sighted consumers, which will lead to lower profits throughout the presale period as the proportion of strategic consumers increases. The product diffusion effect and the proportion of strategic consumers interact to influence the optimal order amount. When the proportion of strategic consumers is below a certain threshold and the positive product diffusion effect is high, the retailer will choose a lower presale price, increasing market demand in both phases and therefore increasing the optimal order amount.




(a) $P_a^*$




(b) D*

Figure 1: Optimal Pricing and Order Amount under the Linear Product Diffusion Effect

As can be seen from Figure 1, the optimal presale price decreases with the increase of the positive product diffusion effect, and with the increase of the negative product diffusion effect. When the negative product diffusion effect is too large, retailers will adapt a premium presale strategy to reduce the demand for products in the presale period. When the product diffusion effect coefficient is constant, and the product availability rate $k$ does not exceed the threshold $k_0$, the retailer will increase the presale price as the proportion of strategic consumers increases.

## *4.2 Convex product diffusion effect*

Assuming $g(D_1)$ is a convex quadratic function on $D_1$ of a convex quadratic function with $g(D_1)$ =$mD_1 - nD_1^2$, where $m > 0, n > 0$ .The larger $m$ , the greater the positive product diffusion effect, the larger $n$, the greater the negative product diffusion effect. Therefore, under the convex product diffusion effect, the retailer's optimal presale price is

$$P_a^* = \frac{(P-c)\left(2n\mu_1\left[v^2 - k\lambda(P-v)^2\right] + v^2(\lambda - m) - Pv\lambda\right)}{2v\left[2(P-c)n\mu_1 + v\right]} + \frac{cv^2 + v^3 - \frac{vk\lambda(P-v)^2}{2}}{2v\left[2(P-c)n\mu_1 + v\right]}$$

**Lemma 4** Under the convex product diffusion effect, the optimal presale price of decreases with the increase of the positive product diffusion effect. When the product's out-of-stock rate $k < k_0$ , the optimal presale price increases with the proportion of strategic consumers, and conversely, the optimal presale price decreases with the proportion of strategic consumers.

By taking the derivative of $P_a^*$ derivative, we obtain

$$\frac{\partial P_a^*}{\partial m} = -\frac{v(P-c)}{2(2n\mu_1(P-c)+v)} < 0, \frac{\partial P_a^*}{\partial \lambda} = 0,$$

we get $k_0 = \frac{2v(P-c)}{(v-P)[2(P-c)n\mu_1+v]}$ , $\frac{\partial^2 P_a^*}{\partial\lambda\partial k} = -\frac{(v-P)^2[2n\mu_1(P-c)+v]}{4v[n\mu_1(P-c)+v]} < 0.$

When $k \le k_0$, $\frac{\partial P_a^*}{\partial \lambda} > 0$, when $k \ge k_0$, $\frac{\partial P_a^*}{\partial \lambda} \le 0$.

At a presale price of $P_a^*$ ,the optimal order amount for the merchant is

$$D^* = (1+m)\mu_1 + \frac{(v-P)(\mu_2 + z\sigma_2) - P_a\mu_1(1-m-\lambda)}{v} - \frac{\lambda\mu_1 P P_a}{v^2} - \frac{\mu_1 P k\lambda(P-v)^2)}{v^3} - \frac{n\mu_1{}^2 A^2}{4v^4}$$

Where $A = 2P_a v + k\lambda(P-v)^2 - v^2$

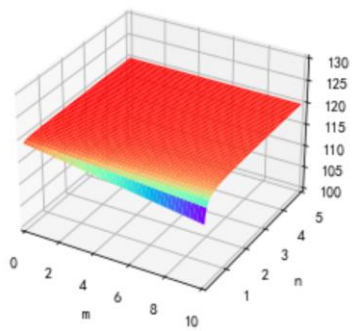
**Lemma 5** In the case of convex product diffusion effects, the optimal order amount decreases as the negative product diffusion effect $n$ increases. When $\lambda < \lambda_0$, the optimal order amount increases with the positive product diffusion effect $m$, on the contrary, the optimal order amount decreases with the positive product diffusion effect.

By taking the derivative of $D^*$ derivative, we obtain

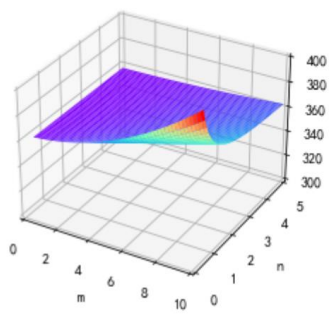
$$\frac{\partial D}{\partial n} = -\frac{\mu_1{}^2 A^2}{4v^4}; \frac{\partial D}{\partial m} = -\frac{A\mu_1}{2v^2};$$

Let $\frac{\partial D}{\partial m} = 0$, get $\lambda_0 = \frac{2v(v-P_a)}{k(P-v)^2}$, and $\frac{\partial^2 D}{\partial m \partial \lambda} = -\frac{k\mu_1(v-P)^2}{2v^2}$.

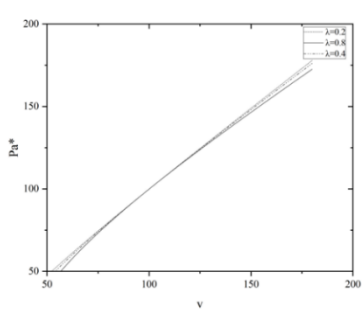
Lemma 4 and 5 analyze the influence of product diffusion effect coefficients $m$ and $n$ on presale pricing and order amount under convex conditions. It is difficult to simultaneously analyze the influence of product diffusion coefficients m and n on presale pricing under nonlinear conditions. The influence of order amount and order amount is discussed below using the method of numerical example analysis. Figure 2(a) shows that when $v = 120$, $P_a^*$ changes with the positive product diffusion coefficient $m$ and the negative product diffusion coefficient $n$, it can be seen that the optimal price $P_a^*$ tends to $v$ . Figure 2(c) shows the change of $P_a^*$ with the upper limit of consumer valuation $v$. $P_a^*$ is proportional to the upper limit of consumer valuation $v$, and is close to the upper limit of consumer valuationUnder convex product diffusion, the presale price is relatively stable. Since the product's presale price determines the product's order amount and expected profit, as shown in Figure 2(b), the optimal order amount and expected profit are also relatively stable If the positive product diffusion effect is large enough and the negative product diffusion effect is minimal, the order amount of the product will increase. Next, analyze the influence of the proportion of strategic consumers and the product availability rate during the regular period on the product presale price. It can be seen from Figure 2(d) that with the increase of the proportion of strategic consumers, different from the situation of linear product diffusion, retailers will reduce the presale price



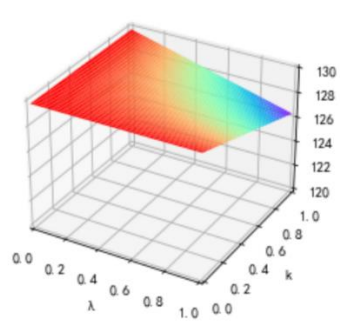

(a)$P_a^*$




(b) $D^*$




(c) $D^*$




(d)$P_a^*$

Figure2 Optimal Pricing and Order Amount under the Convex Product Diffusion Effect

## 5. Conclusions

This paper constructs a model of retailer profitability under a two-stage sales model, considering the strategic behaviour of consumers and the product diffusion effect, and analyzes the optimal presale pricing and order amount of retailers under the scenarios of linear and convex product diffusion effects, respectively, and draws the following conclusions.

1) In the case of the linear product diffusion effect, the optimal presale pricing of a product decreases as the positive product diffusion effect increases and decreases as the negative product diffusion effect increases. When the product's availability in the regular period is no more than a certain threshold, the presale pricing increases with the proportion of strategic consumers. When the proportion of strategic consumers is no more than a certain threshold, the optimal order amount increases with an increase in the positive product diffusion effect and decreases with an increase in the negative product diffusion effect.

2) When considering the convex product diffusion, the optimal presale price tends to be closer to the maximum consumer valuation for different product diffusion effects, unlike when linear diffusion is considered as the proportion of strategic consumers increases and the retailer reduces the presale price. Order amount is also more robust in this case, with order amount increasing more only when the positive product diffusion effect is large, and the negative product diffusion effect is minimal. Other things being equal, order amount increases as the proportion of strategic consumers increases.

In this paper, only the case of single retailer unlimited advance selling has been studied, and the case of quantitative presale has not been considered. Further research can be carried out in the future in the following areas: the retailer's pre-sale pricing model when limited presale is considered; presale strategies in a competitive environment when there are multiple retailers in the market.

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