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Optimal pricing of a new generation product when customers are strategic

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Abstract
In this research, we develop a mathematical model for new generation products in the presence of strategic customers . A firm that produces and sells a two-generation product is considered. It is assumed that potential customers of the first generation are strategic and may delay their purchase to the next generation. The firm aims to determine the optimal price by maximizing total profit. The optimal control theory is used for analyzing the proposed model. The results reveal that strategic behavior influences pricing strategy and reduces optimal price and firm's profit.
Keywords: New generation product, pricing, strategic customers, optimal control theory

1-Introduction
The products life cycle has been shortened under the influence of different factors, including emerging new technologies, changing the needs of customers and increasing competition in the global market. Designing new products and introducing them repeatedly to the market are essential factors of survival in such market. In this regard, if a new product is successful in the market, firms normally replace it with a newer generation whose features have been upgraded. Generation products are numerous such as apparels, mobile phones, TVs, and video game consoles (Anderson et al. 2008; Cenamor et al. 2013; Tsai 2013). To succeed new generations in the market, firms not only must produce them with significant enhancements and new features but also must accurately predict the sales of them over time. An accurate forecast of product sales in the market will help firms in determining appropriate sales policies. Bass proposed the pioneering and most successful diffusion model that described the S-shaped curve of new product diffusion in 1969. He discussed that customers for purchasing a new product are behaving in two manners. A number of them buy the product based on their personal preference (innovators) and others buy the product based on the recommendations of those who bought the product (imitators). Bass considered a fixed number of potential customers and used the hazard rate function for modeling. Norton and Bass at 1987 by inspiring from the Bass model presented a demand growth model for new generation products. They pointed out when two generations exist in the market simultaneously, the newer generation due to advanced features may plunder the customers of the older generation. This phenomenon was considered as the substitution effect (Norton and Bass 1987).

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They did not separate leapfrogging customers from switching customers in the substitution effect. Leapfrogging customers skip the older generation and directly go to the newer one.

Switching customers buy the older generation and are motivated to switch to the newer generation. Jiang and Jain (2012) developed a generalized version of Norton and Bass model by differentiating leapfrogging and switching customers. In all of the classical models, the diffusion of new generation products was considered as S-shaped curve. In 2014, Shi et al. (2014) by referring to demand sales of Apple's products proposed a new diffusion model. They showed that the S-shaped curve could not interpret the diffusion of these products. The sales of the second generation of Apple's PC and iPhone declined immediately after they were launched. The pre-order for iPhone 5 was more than two million just after 24 hours it was released. The analysis of these products revealed that the phenomenon that decreases the sales of one generation or increases the demand more than perception for another, is the strategic behavior of customers. Strategic customers decide which product to buy and when to buy based on the utility that they receive. Shi et al. (2014) chose the time that the older generation is in the market as the main factor of the customers' utility function. In addition to Apple products, the model was empirically validated by using sales demand of the video game consoles of Sony, Nintendo and Microsoft. Results showed that their diffusion model could better predict the sales behavior of generation products than previous diffusion models. Strategic behavior has been observed in various industries (Nair, 2007; Chevalier and Goolsbee, 2009; Hendel and Nevo, 2013; Li et al., 2014; Shi et al., 2014) and up to 70% of customers behave strategically if they have future purchase opportunity (Osadchiy and Bendoly, 2015). Strategic customers do not haste to buy the product and by considering future opportunity, decide about their purchase. They consider current and future opportunities and will either immediately decide to purchase the product or postpone it. In addition to time that one generation is in the market, price is the main factor to evaluate a product in the perspective of customers. There are a large number of marketing and management researches that considered the price as a key factor affecting strategic customers' utility function. Readers are referred to review studies of Chen and Chen 2015; Gönsch et al. 2013; Netessine and Tang 2009; Özer et al. 2012; Shen and Su 2007; Tang 2010 and Zhou and Wu 2011 for more details of these researches. In the context of new generation products, Liang et al. (2014) investigated a pricing model for a two-generation product in the presence of strategic customers. They considered price and innovation level of two generations as factors that influencing the purchase decision of customers. In their model, the prices of two generations were assumed to be a constant and utility-based model was used. Guo and Chen (2018) proposed a diffusion model to analyze the different purchase options of strategic customers. They numerically investigated the optimal pricing and entry time of the next generation. Actually, the impact of strategic behavior on the sales of generation products, despite the empirical evidence of its existence, did not receive much attention in academic researches. It was motivated us to do this research .

In this research, we develop a diffusion model that reasonably describes the effect of strategic behavior. We maximize the total profit of a firm that manufactures and sells a new generation product to strategic customers. The time that current generation exists in the market and the difference between the prices of current and following generation are chosen as the indicators for the possibility of forward-looking behavior. We expand the model of Shi et al. (2014) by considering pricing based on their future research suggestions. The optimal control theory is used to analyze the proposed model. To the best of our knowledge, this is the first research that proposes a diffusion model for new generation products by considering pricing and strategic customers. The researchers, in this research, try to answer these questions: How do we coordinate pricing and strategic behavior in the diffusion model of new generation product? How does strategic behavior vary the pricing strategy of new generation products?

This research is structured as follows: In section 2, the problem is described and the mathematical formulation is presented. The model analysis and solution approach are proposed in section 3. In section 4, numerical examples are solved. Finally, the key findings are outlined and the future research suggestions are expressed in section 5.

2-Model description

In this research, a diffusion model for new generation products is presented. We consider a firm that manufactures and sells a new durable generation product at a monopoly market. The firm releases generation 1 at time 0 and after its life cycle (T), introduces generation 2. The firm determines the optimal price of generation 1 over its life cycle by maximizing the total profit. The potential customers of generation 1 are strategic and may postpone their purchase to generation 2. When they are aware of generation 1 at time t and have positive opinions about it may wait for generation 2. We differentiate between the awareness process and buying process. Let N be the number of potential customers for generation 1. By inspiring from the Bass diffusion model and defining D (P (t)) as the number of customers who are aware of generation 1 and have a positive opinion about it with price P (t) by time t, the awareness rate is as follows:

$$\dot{d}(t) = (a + b\frac{D(t)}{N})(N - D(t))\,\mathrm{G}(P(t)) \tag{1}$$

Where a and b are considered as the coefficient of innovation and the coefficient of imitation, respectively.

In the presence of strategic customers, all customers that have positive opinions about generation 1 will not switch to the final adopters. They evaluate their utility from buying generation 1 or waiting for generation 2. Prices of two generations are important factors influencing on their utility. Also, from the perspective of potential customers, the value of generation 1 decreases over time. So, by getting closer to the introduction time of generation 2, they prefer to wait for it. Thus, the time that generation 1 has existed in the market and the difference between the prices of two generations are chosen as the indicators for the possibility of strategic behavior. By increasing the time and decreasing the difference between the prices of two generations, the possibility of postponing the purchase by the strategic customer will increase. Today, due to the advancement in communication devices, the customers are aware of the new generations and its price even before the introduction of them, particularly in high-technology and consumer electronics markets. We assume that the customers are influenced by the generation 2, immediately after generation 1 is released. By considering these factors as the influential factors of customers' strategic decision and β as the coefficient of strategic behavior, the function $Y(t) = 1 - e^{-\beta\frac{P(t)t}{W}}$ is defined as the likelihood of postponing purchase at time t. Here, parameters W is the price of generation 2 when it will release. Customers that delay their purchase cannot convince others to purchase the generation 1. Therefore, it is supposed that customers who postpone their purchase at time t do not influence other potential customers of generation 1. By considering $G(P(t)) = e^{-\alpha P(t)}$ (Kalish 1983; Şeref et al. 2016), and $Y(t)$, the number of customers that buy the generation 1 at time t is as follows:

$$\frac{\partial S(t)}{\partial t} = \dot{S}(t) = (a + b\frac{S(t)}{N})(N - S(t))e^{-\alpha P(t) - \beta\frac{P(t)t}{W}} \tag{2}$$

The objective function here is defined in equation (3) and is the total profit of the firm. The total profit is considered as the net revenue earned by generation 1 over its life cycle. Parameter C is the production and sales cost for the firm.

$$Max\ z = \int_0^T (P(t) - C)\dot{S}(t)dt \tag{3}$$

$$\dot{S}(t) = (a + b\frac{S(t)}{N})(N - S(t))e^{-\alpha P(t) - \beta\frac{P(t)t}{W}} \tag{4}$$

$$S(0) = 0 \tag{5}$$

$$P(t) \le W \tag{6}$$

Constraint (4) shows the sales of generation 1 at time t. Cumulative sales of generation 1 at time 0 is zero and is presented as the constraint (5). In generation products, a new generation has better features than the older generation. Therefore, it is introduced into the market with a higher price and is considered in constraint (6).

3-Model analysis

Optimal control theory is used to solve the model. In the proposed model, $P(t)$ is the control variable with the maximum value of W and is the state variable. The Hamiltonian function by considering $\lambda(t)$ as the adjoint variable is as follows:

$$H(t) = (P(t) - C + \lambda(t))(a + b\frac{S(t)}{N})(N - S(t))e^{-\alpha P(t) - \beta\frac{P(t)t}{W}} \tag{7}$$

Based on optimal control theory the necessary conditions for optimality are obtained (for clarity, function arguments are omitted). The reader can study the complete description of optimal control theory and its necessary conditions in the work of (Sethi and Thompson 2000).

$$\dot{\lambda} = -\frac{\partial H}{\partial S} = -(P - C + \lambda)(b - \frac{2b}{N}S - a)e^{-\alpha P - \beta\frac{Pt}{W}} \tag{8}$$

With the transversality condition $\lambda(T) = 0$, we have:

$$\lambda(t) = e^{-\frac{W\alpha+\beta}{P}(b-\frac{2bS}{N}-a)e^{-(\alpha+\beta\frac{t}{W})P}} \int_t^T (P - C)(b - \frac{2bS}{N} - a)e^{-\frac{W\alpha+\beta}{P}(b-\frac{2bS}{N}-a)e^{-(\alpha+\beta\frac{Z}{W})P}} dZ \tag{9}$$

For optimal solution, the derivative of H with respect to control variable P is:

$$\frac{\partial H}{\partial P} = 0 \rightarrow (a + b\frac{S}{N})(N - S)e^{-\alpha P - \beta\frac{Pt}{W}} - (\alpha + \beta\frac{t}{W})(P - C + \lambda)(a + b\frac{S}{N})(N - S)e^{-\alpha P - \beta\frac{Pt}{W}} = 0$$

(10)

Then, we have:

$$(a + b\frac{S}{N})(N - S)e^{-\alpha P - \beta\frac{Pt}{W}}[1 - (\alpha + \beta\frac{t}{W})(P - C + \lambda)] = 0 \tag{11}$$

The first part of equation (11) ($(a + b\frac{S}{N})(N - S)e^{-\alpha P - \beta\frac{Pt}{W}}$) is not zero. Furthermore, the last part of equation (11) is equal to zero and gives:

$$(\alpha + \beta\frac{t}{W})(P - C + \lambda) = 1 \tag{12}$$

By solving (13) with respect to P we have:

$$P^* = \frac{W}{\alpha W + \beta t} + C - \lambda \tag{13}$$

Where, λ can be substituted from equation (8) and is a nonlinear function of *α, t, W, C, β* and *P*. It is noticeable that customers' strategic behavior *(β)* decreases the optimal price (*P**).

The second-order derivative is as follows:

$$\begin{aligned}\frac{\partial^2 H}{\partial P^2} &= -2(\alpha + \beta\frac{t}{W})(a + b\frac{S}{N})(N - S)e^{-\alpha P - \beta\frac{Pt}{W}} + (\alpha + \beta\frac{t}{W})^2(P - C + \lambda)(a + b\frac{S}{N})(N - S)e^{-\alpha P - \beta\frac{Pt}{W}} = \\ &(\alpha + \beta\frac{t}{W})(a + b\frac{S}{N})(N - S)e^{-\alpha P - \beta\frac{Pt}{W}}\left[-2 + (\alpha + \beta\frac{t}{W})(P - C + \lambda)\right]\end{aligned} \tag{14}$$

In equation (12), we have $(\alpha+\beta\frac{t}{W})(P-C+\lambda)=1$, furthermore, the second-order derivative is as follows:

$$\frac{\partial^2 H}{\partial P^2}=-(\alpha+\beta\frac{t}{W})(a+b\frac{S}{N})(N-S)e^{-\alpha P-\beta\frac{Pt}{W}}<0$$

Hence, the sufficient condition is satisfied and P^* obtained from equation (13) is the maximum of the profit function.

An important question is which kind of pricing strategy must be used when customers are strategic. To this end, there is a need to characterize the optimal trajectory of price over time for the proposed model. To do this, we considered the following Proposition and its proof.

***Proposition 1*:** when $(W\alpha+\beta t)(b-2bS/N-a)<\beta e^{(\alpha+\beta\frac{t}{W})P}$ the optimal pricing strategy is price skimming and if $(W\alpha+\beta t)(b-2bS/N-a)>\beta e^{(\alpha+\beta\frac{t}{W})P}$, it is penetration pricing. In the $(W\alpha+\beta t)(b-2bS/N-a)=\beta e^{(\alpha+\beta\frac{t}{W})P}$ constant pricing is proposed.

***Proof*:** To get the optimal trajectory of price over time, we take derivative of the optimal price given by $(\alpha+\beta\frac{t}{W})(P-C+\lambda)=1$ with respect to time. After derivation with respect to time and some simplifications, we have (the dot notation is used for the time derivative):

$$\dot{P}+\dot{\lambda}=-\frac{\beta W}{(\alpha W+\beta t)^2} \tag{14}$$

By replacing (9) in to (15):

$$\dot{P}=\frac{(\alpha W+\beta t)e^{-(\alpha+\frac{\beta}{W}t)P}(b-2b\frac{S}{N}-a)-\beta}{(\alpha W+\beta t)^2/W} \tag{15}$$

Equation (15) will be negative and price skimming is optimal if we have:

$$(\alpha W+\beta t)(b-2bS/N-a)e^{-(\alpha+\beta\frac{t}{W})P}<\beta$$

Solve this inequality give:

$$(\alpha W+\beta t)(b-2bS/N-a)<\beta e^{(\alpha+\beta\frac{t}{W})P}$$

Vice versa if $(\alpha W+\beta t)(b-2bS/N-a)>\beta e^{(\alpha+\beta\frac{t}{W})P}$, equation (15) will be positive and the optimal strategy is penetration pricing. When $(\alpha W+\beta t)(b-2bS/N-a)=\beta e^{(\alpha+\beta\frac{t}{W})P}$ equation (15) equals to zero.

If the innovation coefficient is more than the imitation coefficient ($a\geq b$), $(b-2bS/N-a)$ is always negative. Therefore, $(\alpha W+\beta t)(b-2bS/N-a)<\beta e^{(\alpha+\beta\frac{t}{W})P}$ and the firm uses price skimming. In this case, most purchases occur by innovators in the early stages of the generation 1 life cycle when the level of strategic behavior is lower due to the time gap to release generation 2. Therefore, the numbers of sold products in the initiation of the generation 1 life cycle are high and word of mouth effect will increase subsequently. The firm will continue to reduce the price in order to use this position and prevent delays in the purchase.

In the case that the imitation coefficient is more than the innovation coefficient ($b > a$), the statement $(b\text{-}2b\dfrac{S}{N}-a)$ is between zero to one until sales of generation 1 reach maturity and then it will be negative (Kalish 1983), So, $-1<(b\text{-}2bS/N-a)<1$. Besides, we have $(\alpha+\beta\dfrac{t}{W})<e^{(\alpha+\beta\frac{t}{W})}$. P and W are not very different from each other. Hence, we can say $W(\alpha+\beta\dfrac{t}{W})<e^{(\alpha+\beta\frac{t}{W})P}$**.** By multiplying the left and right sides of this inequality in $(b\text{-}2bS/N-a)$ and β, respectively, the direction of inequality may change. It can be said if $\beta>(b\text{-}2bS/N-a)$, it does not change. In other words, in a case that the coefficient of forward-looking behavior (β) is more than word of mouth effect ($(b\text{-}2bS/N-a)$), the firm uses price skimming. Otherwise, the firm must compare the word of mouth effect and strategic behavior before applying the pricing strategy.

4-Numerical study

To solve numerical examples, we consider a market with 2,500 potential customers and life cycle of generation 1 (T) equals to 10. Krishnan et al., (1999) reported that for most products, $a+b$ varies from 0.2 to 1 (Krishnan et al. 1999). It assume a+ b=0.8 and C= 500, W= 750, α= 0.005. It can be seen that numerical examples (table 1) demonstrate the findings of optimal pricing strategies shown in Proposition 1. When more customers are innovators, price skimming is optimal (columns 2 and 3). When b>a, at high strategic behavior level, also, the firm applies price skimming (columns 4 and 5). In column six ($a<b$), the strategic behavior level is low, the firm uses penetration pricing by increasing word of mouth and decreases price when word of mouth decreases. Table 1 shows that by increasing strategic coefficient the optimal price (P*) decreases

Table 1. The optimal trajectory of price

Parameter	**a=0.5, b=0.3**	**a=0.5, b=0.3**	**a=0.2, b=0.6**	**a= 0.2, b= 0.6**	**a= 0.1, b= 0.7**
β	**0.3**	**0.9**	**0.3**	**0.9**	**0.06**
period	**P*(t)**	**P*(t)**	**P*(t)**	**P*(t)**	**P*(t)**
1	657.08	639.02	653.39	638.38	672.63
2	647.70	619.11	644.92	618.80	673.16
3	639.38	604.20	637.31	604.05	673.51
4	631.94	592.61	630.42	592.53	673.70
5	625.26	583.34	624.17	583.30	673.75
6	619.23	575.76	618.48	575.74	673.69
7	613.76	569.45	613.26	569.44	673.50
8	608.77	564.10	608.48	564.10	673.22
9	604.20	559.52	604.07	559.53	672.86
10	600	555.56	600	555.56	672.41

4-1- The effect of strategic behavior

When a firm release a new generation, it knows that some customers may skip this generation and wait for the newer generation. Newer generation always has better features and customers may prefer to buy it later. In this research, we consider the price and the time that current generation has been in the market for this strategic behavior of customers and indicate it with parameter β . The numerical example are solved in two cases: innovation coefficient is more than imitation coefficient ($a>b$) and imitation coefficient is more than innovation coefficient ($b>a$). Numerical examples reveal that a strategic customer is not profitable for the firm and by increasing strategic behavior firm's profit decreases (figures 2 and 4). These findings are in line with previous researches (Anderson and Wilson 2003; Du et al. 2015; Levin et al. 2009).

Where customers are myopic, the firm applies price skimming when $a>b$ (figure 3) and penetration pricing when $b>a$ (figure 1). By increasing the coefficient of strategic behavior, β , the customer's perception to postpone their purchase increases and the firm determines the lower price and reduces it more quickly. It is noticeable that the strategic behavior changes the pricing strategy when $b>a$. It is penetration pricing at first and by increasing the strategic coefficient is skimming (figures 1 and 3).

5-Conclusion

In this study, we explored how a monopolistic firm can best structure the pricing strategy for a new generation product by presenting a diffusion model in the presence of strategic customers. We assumed that potential customers of generation 1 are strategic and may postpone their purchase to generation 2. Strategic customers based on the time that generation 1 has been in the market and the difference between the prices of two generations decide about their purchase. Optimal control theory was used for analyzing the proposed model. The key managerial findings are as follows. First, we proposed a time-variant function for the pricing decision. Being dependent upon the production cost, the coefficient of price on the sales, word of mouth effect, the coefficient of strategic behavior, the price of generation 2, and the time of availability of generation 1 in the market.

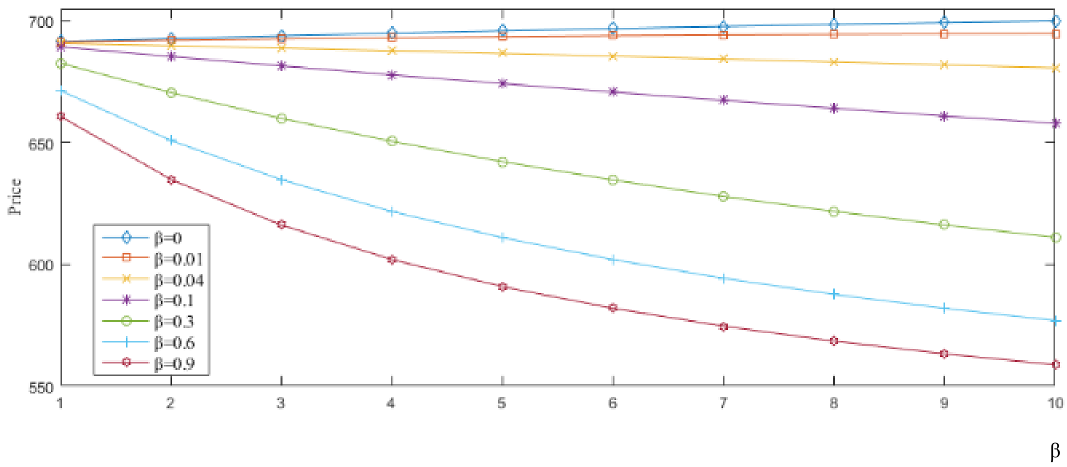

Fig. 1. The optimal trajectory of price with respect to β at a=0.3, b=0.5

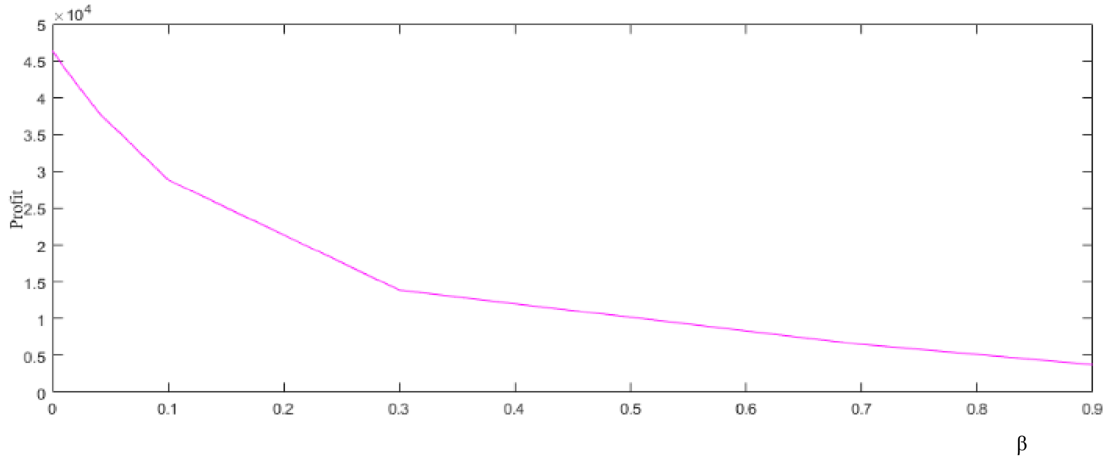

Fig. 2. The profit of the firm with respect to β at a= 0.3, b=0.5

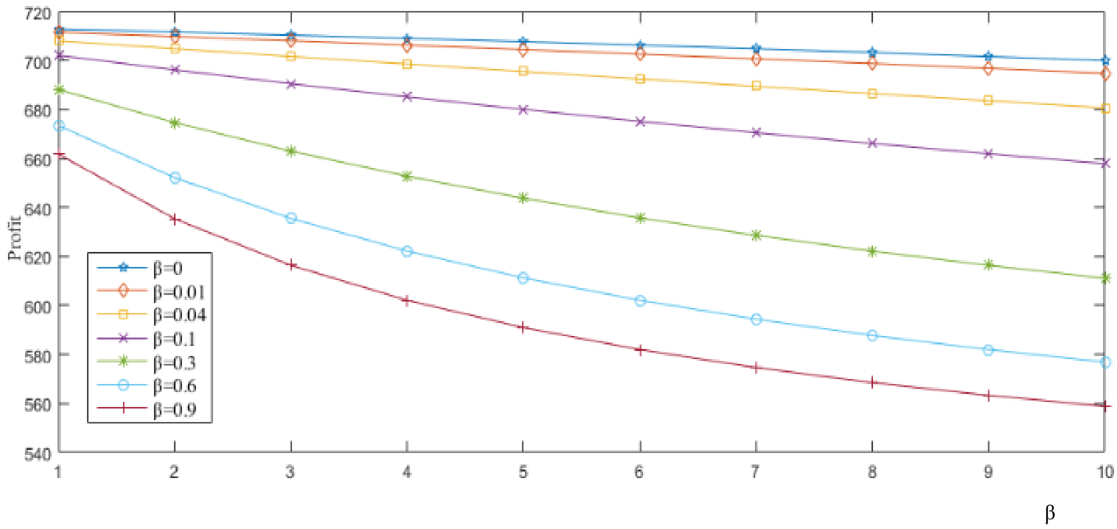

Fig. 3. The optimal trajectory of price with respect to β at a=0.5, b=0.3

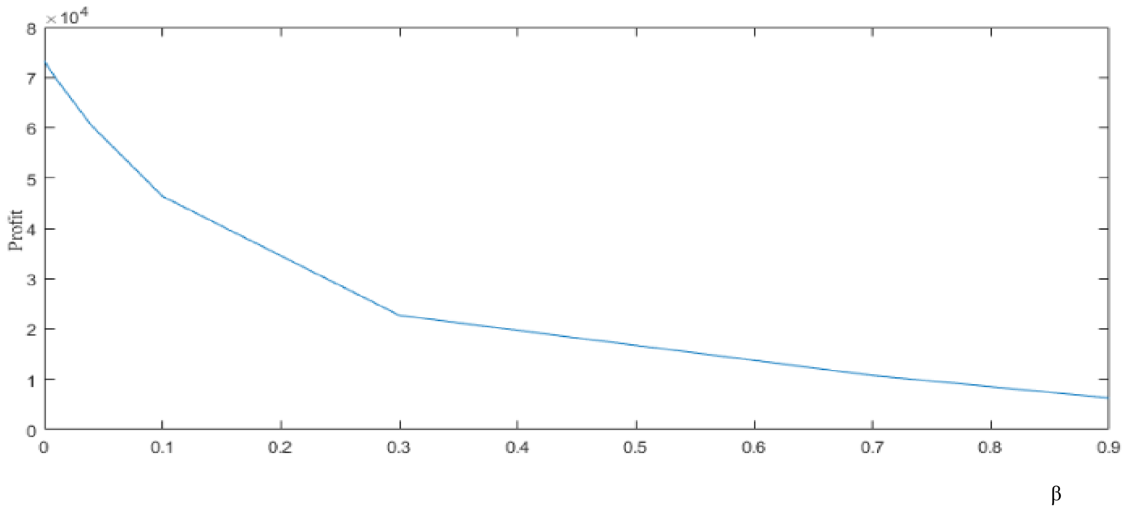

Fig. 4. The profit of the firm with respect to β at a= 0.5, b=0.3

Second, strategic behavior decreases the optimal price and the firm's total profit. Third, our analysis pointed out that the firm must use price skimming strategy when the innovation coefficient is more than imitation coefficient. If the imitation coefficient is more than innovation coefficient, the pricing strategy will depend on the impact of strategic behavior and word of mouth.

In real words, some generation products of brand firms such as the tablet computer and smartphone of Apple are monopolistic in their markets. Our research problem can be used as a practical model for modeling and predicting the diffusion of these products. However, if there is a rival in the market, customers may postpone their purchase to the next generation of rivals. Therefore, this model can be extended by considering competition in the market. Here, we modeled the pricing of just generation 1, by considering two generations, the proposed model becomes more practical. The reason is that when strategic behavior reduces the sale of generation 1, may increase the sale of generation 2. So, modeling the pricing of them simultaneously can give the managers a better view in their decision making. In addition, the proposed model becomes more practical by considering another marketing decisions such as advertising.

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