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Pricing strategies and decisions in a Bertrand competition with Markov process

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***Abstract*—In this paper, we consider that consumers have memory about their previous purchases, and thus consumers' switching behavior is associated with the gap of consumer perception. In such an environment, we investigate the interaction of the periodically pricing strategies between a brand manufacturer and a generic manufacturer, who sell homogeneous consumable products in the market, in a two-period supply chain. We formulate consumers' Markovian switching behavior by using utility functions to obtain market demand for each manufacturer. Subsequently, we derive the manufacturers' equilibrium pricing decisions and profits. Then, we resort to the numerical analysis to explore the parametric effects on the equilibrium results in order to provide the managerial insights.**

I. Introduction

Consumers' behavior associated with brand switching and their brand preference has drawn much attention in the literatures [1]–[3]. According to a Gartner report, the global smartphone market presents duopolistic competition between Apple Inc. and Samsung Inc., who obtained 17.8% and 29.5% market share in Q4 of 2013, respectively [4]. Moreover, with the saturation in the smartphone market, consumers' switching behavior is mainly between these two brands. A report conducted by CIRP showed that 42% users purchased iPhones and 38% users purchased Samsung phones planned to change their phones from July 2012 through June 2013, and moreover, 33% users who purchased iPhones were switching from Samsung phones and 11% users who purchased Samsung phones were switching from iPhones [5]. Thereupon, how to stimulate consumers' purchase in the competition from main rivals is a key element affecting companies to determine their strategies and operational decisions.

We consider a supply chain consisting of two chain members over two periods. A brand firm produces and sells a high quality product to the market during two periods, and a generic firm produces low quality product and participates in the market based on brand firms prices decision in the first period. Thus, the price competition between the brand firm and the generic firm arises in the first period. In second period, a generic firm stay in market depends on the prices of brand firm. In addition, sales pricing attribute is an important factor to trigger consumers' switching behavior [6], [7]. As a result, we develop a two-period model to examine consumers' switching behavior as a Markovian process, and characterize equilibrium pricing decisions and profits of the competition between a brand manufacturer and a generic manufacture. Price competition and consumers' purchase choice between two products have been widely considered in the literature. For example, in [6], a multi-period model is formulated to discuss price and quality decisions in a duopolistic competition between two manufacturers who face strategic consumers. Price and quality decisions have been discussed in a duopolistic competition between two manufacturers who chooses to provide low- or high-quality products while facing variety-seeking consumers [7]. Moreover, in [8], the authors studied consumers' perception with regard to two retailers by adopting utility functions and further explored the influences of consumers' long-term perception on retailers' pricing decisions and profits at equilibrium. However, these studies implied that consumers are memory less of their past usage experiences. A multi-period model is developed to discuss retailers' decisions of ordering quantities placed to a supplier's based on their past experiences of the supplier's fill rates [9]. The authors further probed into the relationships between the retailers' ordering decisions and the supplier's capacity decisions and the firms' profitability. In this study, we discuss manufacturers' pricing decisions and strategies while considering consumers' switching behavior depends on their experiences by developing a two-period model. Nevertheless, in the aforementioned studies, the authors considered the assumptions that the firms' pricing strategies vary depending on single period conditions, and thus the firms do not alternate their prices periodically. In this study, we examine that the consumers' Markovian behavior as well as the firms' periodical pricing strategy that is a common promotional action in reality. As a result, this study contributes to the literature on formulating consumers' two-period Markovian behavior, firms' periodically pricing strategy, and investigating the firms' equilibrium decisions in a operational and strategic games.

II. The Model

Consider a supply chain model consisting of two asymmetric firms, indexed by i, $i = b, g$. Firm b offers higher quality products than firm g, and both the firms compete on prices in a market with A consumers who are price sensitive and make their purchasing decisions based on the last experiences. We examine the firms' pricing strategies as well as consumer purchasing behavior. To investigate the interaction on the firms' pricing strategies, we create a two-stage game where the firms choose their pricing strategies in the first stage, and determine the price decisions in the second stage. In each of the two stages, the firms play a simultaneous-move noncooperative game with complete information [10]. In the first stage, each firm is endowed with two pricing strategies: either to use a fixed price over selling periods (denoted by Strategy F), or to alternate between two different prices periodically (denoted by

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Strategy A). Thereby, four subgames can potentially emerge. As is typical for such a strategic-form game, the firms' equilibrium choices can be obtained by considering the best response functions of each firm given the pricing strategy of the other firm. The superscript j, $j \in \{AA, FA, AF, FF\}$, refers to the type of subgame which the firms play, and the first and second letters of the superscript denote firm b's and firm g's pricing strategies, respectively. In the second stage, the firms choose their prices simultaneously. When firm i adopts to fix the price over periods, i.e., Strategy F, it chooses a single price decision; when it adopts to alternate the prices periodically, i.e., Strategy A, it chooses two different price decisions, a regular price and an adjusted price.

A. Consumer Model

Regarding consumer purchasing behavior, consumers make their purchasing choices among no purchase, firm b's product and firm g's product based not only on the sales prices but also on the perception of quality, performance, and satisfaction received from the past experience. Each consumer in the market choose to not purchase or purchase only one unit in each period from the firm that gives the highest utility in that period. The consumers have to reconsider their purchases every period because the product purchased in the previous periods does not deliver positive utility for the consumer in the next period, i.e., a product has a useful lifetime of single period [1], [2]. We formulate that the consumers determine their purchasing choices in a Markov process. We let $j \in \{b, g, l\}$ denote the state of the consumers' purchasing choice, where b (g) represents that the consumers choose firm b's (firm g's) product and l represents that the consumers choose neither of the products. We let β represent the perception gap that is incurred when a consumer purchases the product that is different from the his last purchase. If a consumer who originally purchased product g switches to product b, he will receive a perception increase β because of the superior quality of product b; on the contrary, he will receive a perception decrease $-\beta$. Specifically, the utility received by a consumer is $U_{bg} = \rho\theta - P_g - \beta$ when he switches from product b to product g, and on the contrary, is $U_{gb} = \theta - P_b + \beta$ when he switches from product g to product b, where P_j stands for the price chosen by firm j and ρ, $0 < \rho < 1$, stands for the initial valuation discount resulted from the quality decrease of product g compared to product b. However, when a consumer does not make the switch or does not purchase in the pervious period, his utilities of product b and g are $U_{bb} = U_{lb} = \theta - P_b$ and $U_{gg} = U_{lg} = \rho\theta - P_g$, respectively, because lack of perception gap or the previous experience. A consumer who can not get positive utility from products b and g will not make the purchase.

We express the consumers' decision process as a 3-state Markov process where the transition probabilities can be derived from consumer utility functions. We take consumers who purchased product g in the last period as an example, and each of these consumers make the purchase decisions among state $k \in \{l, b, g\}$ that provides the highest utility. Hence, these consumers switch to product b if purchase product b if $U_{gb} > U_{gg}$, keep their purchases of product g if $U_{gg} > U_{gb}$ and $U_{gg} > 0$, or do not make purchase if $U_{gg} < 0$. We have $U_{gb} > U_{gg} \Rightarrow \theta > \theta^* = (P_b - \beta - P_g)/(1-\rho)$ and $U_{gg} > 0 \Rightarrow \theta > \underline{\theta} = P_g/\rho$. Thus, we can obtain the transition probability, δ_{gk}, from state g to state $k \in \{l, b, g\}$.The transition probabilities from states l and b can be derived in the same way. Hence, we obtain the following transition matrix:

$$
\begin{aligned}
\boldsymbol{M} &= \begin{pmatrix} \delta_{ll} & \delta_{lb} & \delta_{lg} \\ \delta_{bl} & \delta_{bb} & \delta_{bg} \\ \delta_{gl} & \delta_{gb} & \delta_{gg} \end{pmatrix} \\
&= \begin{pmatrix} \dfrac{P_g}{\rho} & 1 + \dfrac{P_g - P_b}{1-\rho} & \dfrac{P_g - \rho P_b}{(\rho-1)\rho} \\ \dfrac{\beta + P_g}{\rho} & 1 + \dfrac{\beta - P_b + P_g}{1-\rho} & \dfrac{\beta - \rho P_b + P_g}{(\rho-1)\rho} \\ \dfrac{P_g}{\rho} & 1 + \dfrac{\beta - P_b + P_g}{1-\rho} & \dfrac{\rho P_b - \beta\rho - P_g}{(1-\rho)\rho} \end{pmatrix} \quad (1)
\end{aligned}
$$

III. THE STEADY-STATE MARKET SHARE AND SUBGAME-PERFECT NASH EQUILIBRIUM DECISIONS

We let d_k and $\hat{d}_k$ be the steady-state market share of state k after implementing price p_i and $\hat{p}_i$, respectively. Under the alternating Markovian process, the relationship between the steady-state market shares and the firms' price decisions must satisfy the following equations: $\sum_k d_k = 1$,

$$
\begin{aligned}
\begin{pmatrix} d_l & d_b & d_g \end{pmatrix} &= \begin{pmatrix} \hat{d}_l & \hat{d}_b & \hat{d}_g \end{pmatrix} \boldsymbol{M}|_{P_i = p_i}, \quad \text{and} \quad (2) \\
\begin{pmatrix} \hat{d}_l & \hat{d}_b & \hat{d}_g \end{pmatrix} &= \begin{pmatrix} d_l & d_b & d_g \end{pmatrix} \boldsymbol{M}|_{P_i = \hat{p}_i}. \quad (3)
\end{aligned}
$$

The firms' objectives can be written as follows:

$$
\begin{aligned}
\max_{p_b, \hat{p}_b \geq 0} \Pi_b^j &= (p_b - c - \lambda\,\Gamma_b) d_b^j + (\hat{p}_b - c)\hat{d}_b^j, \quad \text{and} \\
\max_{p_g, \hat{p}_g \geq 0} \Pi_g^j &= (p_g - \phi\, c - \lambda\,\Gamma_b) d_g^j + (\hat{p}_g - \phi\, c)\hat{d}_g^j,
\end{aligned}
$$

where λ is the cost for lunching the price alteration in the next period, and Γ_i is an indicator to represent whether firm i alternates the price periodically, i.e., $\Gamma_i = 0$ if firm i chooses Strategy A and 0 otherwise.

We now determine the subgame-perfect Nash equilibrium (SPE) decisions and profits of the four subgames (*FF*, *FA*, *AF*, and *AA*). Throughout the paper, we let superscript "*" designate the equilibrium values.

We proceed to determine the subgame-perfect Nash equilibrium (SPE) decisions and profits. First, We focus on Subgame *AA* in which both the firms alternate their prices. Under the alternating Markovian process, the steady-state market share must satisfy $[d_l \;\; d_b \;\; d_g] = [\hat{d}_l \;\; \hat{d}_b \;\; \hat{d}_g] \cdot \boldsymbol{M}|_{p_b = p_b, p_g = p_g}$ and $[\hat{d}_l \;\; \hat{d}_b \;\; \hat{d}_g] = [d_l \;\; d_b \;\; d_g] \cdot \boldsymbol{M}|_{p_b = \hat{p}_b, p_g = \hat{p}_g}$ The solution of the steady-state market shares of states b and g under Subgame *AA* is given by

$$
\begin{aligned}
d_b^{AA} &= \frac{\rho(\beta - p_b + p_g - \rho + 1) - \beta\hat{p}_g}{\beta^2 - \rho^2 + \rho}, \\
d_g^{AA} &= \frac{p_b\rho + \beta(\hat{p}_b - 1) - p_g}{\beta^2 - \rho^2 + \rho}, \\
\hat{d}_b^{AA} &= \frac{\rho(\beta - \hat{p}_b + \hat{p}_g - \rho + 1) - \beta p_g}{\beta^2 - \rho^2 + \rho}, \\
\hat{d}_g^{AA} &= \frac{\beta(p_b - 1) + \hat{p}_b\rho - \hat{p}_g}{\beta^2 - \rho^2 + \rho}.
\end{aligned}
$$

Similar to Subgames *FA* and *AF*, the objectives of firm b and firm g are to maximize the sum of their profits under steady-state market shares d and $\hat{d}$, as follows:

$$\max_{p_b,\hat{p}_b\geq 0} \Pi_b^{AA} = (p_b - c - \lambda)d_b^{AA} + (\hat{p}_b - c)\hat{d}_b^{AA}, \quad \text{and}$$
$$\max_{p_g,\hat{p}_g\geq 0} \Pi_g^{AA} = (p_g - \phi\, c - \lambda)d_g^{AA} + (\hat{p}_g - \phi\, c)\hat{d}_g^{AA}.$$

The equilibrium prices under Subgame AA can be obtained as follows:

$$p_b^{AA} = \frac{\beta^2 + \beta(\rho - c\phi) + \rho(c(\phi+2) + 3\lambda - 2\rho + 2)}{\beta^2 - (\rho-4)\rho},$$
$$p_g^{AA} = \frac{\rho\left(\beta^2 + \beta(c-1) + \rho(c+\lambda-\rho) + 2c\phi + 2\lambda + \rho\right)}{\beta^2 - (\rho-4)\rho}$$
$$\hat{p}_b^{AA} = \frac{\beta^2 - \beta(c\phi + \lambda - \rho) + \rho(c(\phi+2) - 2\rho + 2)}{\beta^2 - (\rho-4)\rho}, \quad \text{and}$$
$$\hat{p}_g^{AA} = \frac{\rho\left(\beta^2 + \beta(c+\lambda-1) + \rho(c-\rho) + 2c\phi + \rho\right)}{\beta^2 - (\rho-4)\rho}.$$

Under Subgames FA and AF in which a firm chooses Strategy F to fix a price over periods, but the other firm chooses Strategy A to alternate the price between two different levels periodically. To differentiate the prices of firm i who alternates the prices periodically, we let p_i and $\hat{p}_i$ be firm i's two prices, and d_k and $\hat{d}_k$ be the steady-state market share of state k after implementing price p_i and $\hat{p}_i$, respectively. Following the works of [11], [12], we formulate the decision process in an alternating Markov chain. Thus, the steady-state market share must satisfy the following equations:

$$\begin{pmatrix} d_l & d_b & d_g \end{pmatrix} = \begin{pmatrix} \hat{d}_l & \hat{d}_b & \hat{d}_g \end{pmatrix} \boldsymbol{M}|_{p_i=p_i} \quad \text{and}$$
$$\begin{pmatrix} \hat{d}_l & \hat{d}_b & \hat{d}_g \end{pmatrix} = \begin{pmatrix} d_l & d_b & d_g \end{pmatrix} \boldsymbol{M}|_{p_i=\hat{p}_i}.$$

For optimizing the steady-sate performances, firm b and firm g aim to maximize the sum of their profits under steady-state market shares d and $\hat{d}$, as follows: Under Subgame FA,

$$\max_{p_b\geq 0} \Pi_b^{FA} = (p_b - c)d_b^{FA} + (p_b - c)\hat{d}_b^{FA}, \quad \text{and}$$
$$\max_{p_g,\hat{p}_g\geq 0} \Pi_g^{FA} = (p_g - \phi\, c - \lambda)d_g^{FA} + (\hat{p}_g - \phi\, c)\hat{d}_g^{FA};$$

moreover, under Subgame AF,

$$\max_{p_b,\hat{p}_b\geq 0} \Pi_b^{AF} = (p_b - c - \lambda)d_b^{AF} + (\hat{p}_b - c)\hat{d}_b^{AF}, \quad \text{and}$$
$$\max_{p_g\geq 0} \Pi_g^{AF} = (p_g - \phi\, c)d_g^{AF} + (p_g - \phi\, c)\hat{d}_g^{AF}.$$

The concavity of Π_b and Π_g in the price decisions assures that the simultaneous solution of the first-order conditions gives the firms' unique equilibrium prices. Under Subgame FA, we obtain

$$p_b^{FA*} = \frac{(\beta-\rho)(2\beta - 2c\phi - \lambda + 4\rho) + 4(c+1)\rho}{2\left(\beta^2 - (\rho-4)\rho\right)},$$
$$p_g^{FA*} = \frac{\beta^2(\lambda+4\rho) + 4\beta(c-1)\rho + \rho\left(4\left(c\rho + 2c\phi - \rho^2 + \rho\right) - \lambda(\rho-8)\right)}{4\left(\beta^2 - (\rho-4)\rho\right)},$$
$$\hat{p}_g^{FA*} = \frac{-\beta^2(\lambda-4\rho) + 4\beta(c-1)\rho + \rho(\rho(4c+\lambda-4\rho+4) + 8c\phi)}{4\left(\beta^2 - (\rho-4)\rho\right)};$$

under Subgame AF, we have

$$p_b^{AF*} = \frac{\beta^2(\lambda+4) + 4\beta(\rho - c\phi) + \rho(4c(\phi+2) - (\lambda+8)\rho + 8(\lambda+1))}{4\left(\beta^2 - (\rho-4)\rho\right)},$$
$$\hat{p}_b^{AF*} = \frac{8(c+1)\rho - (\beta-\rho)(\beta(\lambda-4) + 4c\phi + (\lambda-8)\rho)}{4\left(\beta^2 - (\rho-4)\rho\right)}, \quad \text{and}$$
$$p_g^{AF*} = \frac{\rho\left(2\beta^2 + \beta(2c+\lambda-2) + \rho(2c+\lambda-2\rho+2) + 4c\phi\right)}{2\left(\beta^2 - (\rho-4)\rho\right)}.$$

By the analogues approach, the equilibrium results of the rest scenarios can be obtained, and thus, we omit the derivations. Taking all the equilibrium prices into the market-share and profit functions, the equilibrium market share ($d_i^{j^*}$ and $\hat{d}_i^{j^*}$), and the equilibrium profits ($\Pi_i^{j^*}$) can be obtained.

IV. Numerical analysis

In this section, we investigate the sensitivity of the equilibrium results and examine the impacts of parametric changes on the firms' decisions and profits. Further, we probe into the equilibrium choices of the strategic game. Further, we reveal the firms' equilibrium strategy in a strategic-form game. To further study the parametric effects on the firms' equilibrium behavior in the strategic game, we employ numerical approaches. In the numerical experiments, we consider the base example with $\beta = 0.05$, $\rho = 0.6$, $\lambda = 0.1$, $\phi = 0.6$, and $c = 0.2$, and vary the parametric values of the base example. Because the initial valuation discount ρ of product g and product g's cost discount factor ϕ have more significant impacts than other parameters, we focus on the parametric effects on these two factors in the following analysis.

In Figure 1, we show the effect of ρ on the equilibrium prices. As the general phenomena shown in the Figure 1, the firms will lower their prices in the next period if they opt to alternate the prices, and when the consumers values the generic products with higher valuation, the brand manufacturer will lower their prices in response, and however, the generic manufacturer will initially increase and then decrease the price. This is because the consumers' higher valuation toward the generic products strengthes manufacturer g's competitiveness. Moreover, we observe that if the firms choose to alternate the prices periodically, the price competition will be slacken, and thus the firms' prices at equilibrium will increases. Such a phenomenon is more significant when firm b adopts Strategy A.

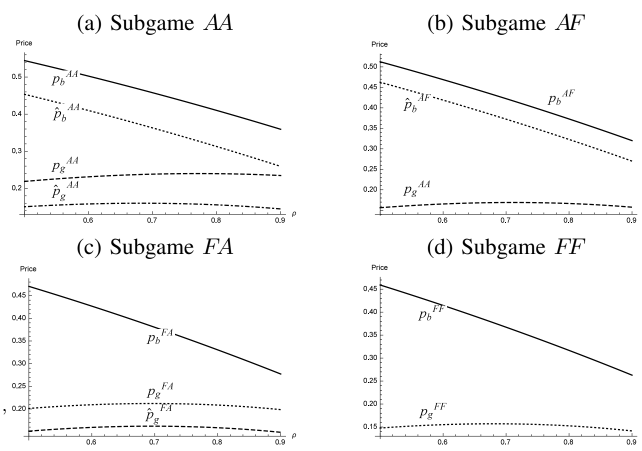

Fig. 1. Effect of the initial valuation discount ρ of product g on the equilibrium prices under subgames

Figure 2 depicts the impacts of ϕ on the firms equilibrium prices. Moreover, we find that all the firms will increase their prices when generic products is costly. This is due to that the increasing cost stimulates firm g to raise the sales prices, and then softens the price competition. Compared to Figure 1, we can observe that the equilibrium prices is more sensitive to ρ, indicating that efforts on stimulating consumers' valuation is more effective than on decreasing production cost in the view of firm g.

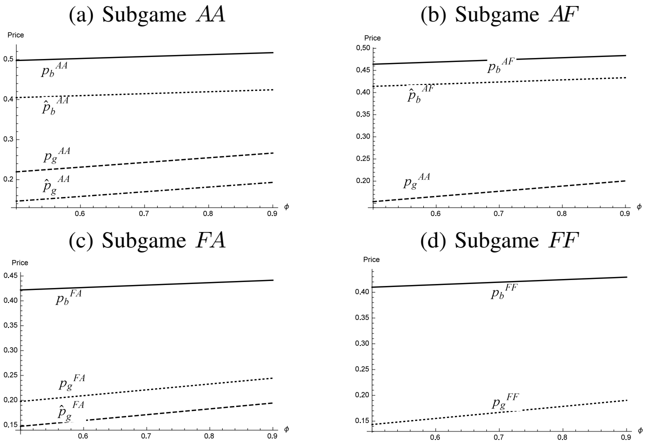

Fig. 2. Effect of product g's cost discount factor ϕ on the equilibrium prices under subgames

Figure 3 shows the parametric effects on firm b's profits are monotonic, but those on firm g's profits are varied. In Figure 3(a), firm b's profits decrease in ρ, because the generic products are more competitive. Moreover, fixing pricing strategy over periods is more beneficial to firm b. Figures 3(b) reveals that when the firms choose identical strategies (i.e., Subgames AA and FF), firm g's equilibrium profits will initially increase and then decrease in ρ, and however when the firms choose asymmetric strategies (i.e., Subgames AF and FA), firm g's equilibrium profits increase in ρ. Additionally, Subgame AF is beneficial to firm g, and Subgame FA is more profitable to firm g when ρ is greater. Regarding the impacts of ϕ on the firms' equilibrium profits, we in Figure 3(c)-(d) find that firm b's profits always increase in ϕ because firm g's production cost increases. However, for firm g, when adopting Strategy F, firm g's profits decrease in ϕ, but when choosing Strategy A, firm g's profits will initially decrease and then increase in ϕ. These results indicate when firm g bears the greater production cost, it is more profitable for him/her to alternate the price periodically, especially in the case when firm b chooses Strategy F.

In the above analysis, we have illustrated the parametric effects on the firms' prices and profits at equilibrium. We now turn the attention to the parametric effects on the firms' equilibrium choices of the pricing strategy in a strategic-form game. Figure 4 shows that when ϕ is large, alternating the price periodically will be the equilibrium choice for firm g, however fixing the price over periods is a dominant strategy for firm b. Thus, we can observe that two possible strategic choices, i.e., FA and FF. In addition to ϕ, ρ also has impact on firm g's pricing preference; that is, the small or great levels of ρ increase firm g's preference to adopt Strategy A.

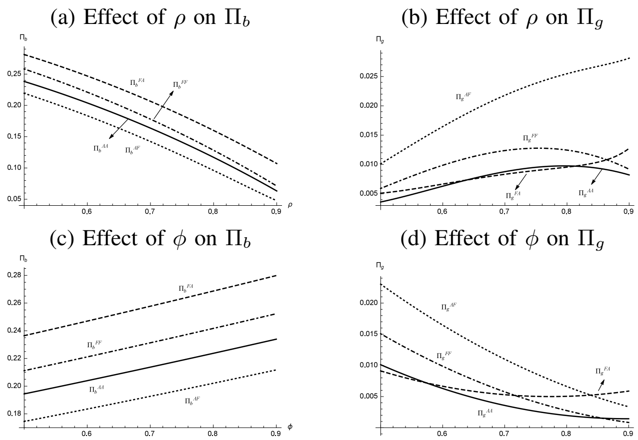

Fig. 3. Parametric effects on the equilibrium profits under all of the subgames

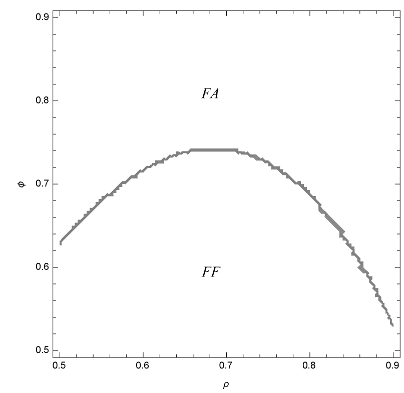

Fig. 4. Firms' equilibrium strategy in a strategic-form game

V. Summary

This paper developed a two-period model to formulate the consumers' switching behavior with respect to the firms' periodical pricing strategies, and investigated the parametric impacts on the equilibrium decision and profits under the duopolistic competition between a brand manufacturer and a generic manufacturer. Moreover, we numerically analyze the trends of the equilibrium results. Finally, several observations regarding the manufacturers equilibrium decisions and profits are discovered. For example, the firms will lower their prices in the next period if they opt to alternate the prices. We find that alternating the price periodically will slacken the price competition, and thus the firms' prices at equilibrium will increases. The equilibrium decisions and profits are more sensitive to the consumers' valuation discount, indicating that firm g is suggested to focus the efforts on stimulating consumers' valuation rather than decreasing production cost. Regarding the strategic choices of the firms, fixing pricing strategy over periods is a dominant to firm b, and alternating the pricing strategy is a superior strategy to firm g when the production cost is high or when the consumer valuation discount is at low or high levels. Hence, two possible equilibrium choices FA and FF emerge.

The following are the possible extensions of our study for a better understanding of periodical pricing strategy. First, another possible direction is to extend our model to be stochastic by considering the uncertainties of the consumer demand and however, this direction would increase analytical complexities as it requires the restructuring of current models. Second, it will be interesting to distinguish consumers between new and existing consumers. The existing consumers determine their purchasing choices based on prices as well as their past experience. Such a consideration is plausible and allows us to investigate the interactions of quality or after-sales efforts between brand and generic manufacturers.

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