First-mover advantages: flexible or not?

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ABSTRACT

This paper explores the impact of two operational issues, product flexibility and production cost, on first-mover advantages and product design decisions in a myopic duopoly setting. This research determines each firm's optimal design policy and provides criteria under which the first entrant enjoys first-mover advantages. The results show that it is not always beneficial for the first mover to have product flexibility when both firms are myopic. Another interesting result is when the first mover has more flexibility both firms benefit but the late mover may derive higher benefit.

Keywords: first-mover advantage, first-mover disadvantage, product flexibility, operation management

1. INTRODUCTION

In today's rapidly changing business world, firms are facing more and more challenges. When developing new products, they not only have to decide the variety and performance of these new products, but must also consider the effects of time-to-market, the degree of flexibility of their operations, and their competitors' strategies.

Traditionally, pioneers are considered to have first-mover advantages, which mainly are higher market shares and higher profits than late entrants (Urban, et. al 1986, Lieberman and Montgomery 1988). However late entrants have less risk in product development, and often can more easily implement new technologies, thus achieving lower production costs. The situation is even more complicated when firms try to foresee their competitors' moves while making their own decisions. Emerging new technologies have made production processes more flexible, allowing firms to adjust their product mix and production volumes in response to competitors' actions. These advantages and disadvantages usually manifest in a multi-period decision-making environment.

This paper investigates the impact of two operational issues, product flexibility and production cost, on first-mover advantages and product design decisions in an environment where customers are making repeat purchases. The paper considers the issue of product introductions in a duopoly setting and the time horizon is divided into three periods. Two firms enter the market sequentially. Competition starts from the beginning of the second period when the late mover enters the market. In the third period, the first mover has a chance to adjust its product, incurring a switching cost, which depends on the flexibility of the firm. Thus the flexibility considered is product flexibility when higher flexibility implies lower switching cost.

Using a game-theoretical model, the paper shows when duopoly is myopic: How the first mover's positioning and pricing strategies change from the first period to the third period; How the optimal strategies of the first mover change with different production costs and product flexibility; How these issues affect the other firm's product design strategies and timing of entry. This paper checks the effects of product flexibility and production cost on the firms' market shares and profits and provides criteria under which the pioneer enjoys first-mover advantages.

In the next section, the extant literature is reviewed. Models are described in Section 3. Section 4 summarizes the research and suggests directions for further work.

2. LITERATURE REVIEW

This research encompasses three important issues, first-mover (dis)advantages, time-to-market, and product flexibility.

Existing work approaches first-mover advantages from a number of different perspectives. Lieberman and Montgomery (1988, 1998) define first-mover advantages as the pioneer's ability to earn profit. They identify the mechanisms that lead to first-mover (dis)advantages. These mechanisms often arise from the endogenous nature of first movers. There is a considerable amount of theoretical and empirical work lending support to the notion that, generally the first mover enjoys a permanent market share advantage and, further, that there is a positive correlation between market share and order of entries of all competitors (Urban, et. al 1986, Lambkin 1988, Kalyanaran and Urban 1992, Golder and Tellis 1993, Brown and Lattin 1994, Bowman and Gatignon 1996, Lee, et. al 2000). This paper supports this result by showing that the pioneer usually retains higher market share whether or not it attempts to foresee its competitor's strategy.

Entry timing often plays an important role in whether a new product succeeds. Many papers model product development level as a function of entry time and study the trade-off between them. Morgan, et. al (2001) analyze a multi-generation product development problem with fixed and variable development costs. In their model, a firm enters the market later but products are introduced more frequently than in the single period model. With multiple generations, fixed costs play a more important role in product development cycle time; In their single generation model, variable costs are more important. Klasorin and Tsai (2004) further extend the research by assuming that the order of entry is a function of two competitors' product design levels and capabilities. The first entrant enjoys a monopoly period, but once the duopoly situation begins, both firms set their prices simultaneously with knowledge of each other's product design level. The expected price competition forces the firms to position their products far away from each other. This model shows that the first mover does not always achieve greater market share or earn more profit. Assuming the competitor's production cost is a decreasing function of time-to-market, this research confirms that the pioneer may not have first-mover advantages if its production cost is much larger than the late entrant's.

A firm's ability to adapt to changes is important to its success. Manufacturing flexibility has many dimensions and product flexibility is one of the most important ones. Work on product flexibility has been very fruitful. As suggested in Röller and Tomback (1993), and Goyal and Netessine (2006), firms often use product flexibility as a weapon to respond to competition. Almost all existing literature concludes that firms with product flexibility will implement it once they enter a market, with or without the presence of competitors. In this paper, the pioneer company defers the use of product flexibility until it observes the competitor's strategies. Thus the first entrant fully exploits the advantages of being the pioneer and then uses flexibility later as a competitive weapon. Product flexibility allows the first mover to respond to the entry of a competitor by switching from the current product to a new one. This research explores the impact of the first mover's switching cost on product design decisions and first-mover advantages. The total switching cost is not fixed but related to both the original product decision as well as the new one. This paper shows that, in a duopoly market, it may not always be optimal for the pioneer company to use product flexibility as a competitive weapon. This finding is consistent with extant empirical studies.

3. MODEL

Consider two firms, A and B, competing on one attribute, to which is referred as “quality”. Both firms have full knowledge about each other: they know each other's cost and can foresee each other's move. Each firm wants to determine its product position and price to maximize its total profit over a finite time horizon.

A three-period model is developed, which incorporates the firms' positioning and pricing strategies. Let the price offered by firm i in period j be p_{ij}, where $i \in \{A, B\}$ denotes the firms and $j \in \{1,2,3\}$ denotes the periods. Let q_{A1}, q_{A3} denote firm A's product qualities in period 1 and 3 respectively and q_B denotes firm B's product quality. Firm A, a monopolist in the first period, first enters the market by introducing a new product with quality q_{A1} and price p_{A1} at time 0. Firm B chooses a time to enter the market, denoted by α, positions its product at q_B, and charges a price of p_{B2}. Firm B's entry marks the beginning of the second period. Firm A responds to firm B's entry in two ways. First as a quick response, firm A changes its price to p_{A2} at time when firm B introduces its product. Next after a length of time, denoted by β firm A adjusts its product design to q_{A3} and price to p_{A3} to gain a better position in the market. However, it incurs a switching cost for changing its product position. This change at time $\alpha+\beta$ marks the beginning of the third period. Firm B may also change its price to p_{B3} at time $\alpha+\beta$ in response to firm A's changes. Figure 1 (Appendix) depicts the timeline of events and associated decisions.

To set the setting in business context, consider this example: In 1985, Nintendo released its revolutionary video game console Nintendo Entertainment System (NES), which made Nintendo the market monopolist. Until the late 1980s, the NES enjoyed tremendous popularity and monopoly. In 1989, Sega entered the market as a competitor after the debut of its new video game console, whose superior graphics and sound performance helped Sega make significant gains against Nintendo in the early 1990s. In response to Sega's presence, Nintendo released cheaper versions of NES. But it was not until two years later that Nintendo finally released its next-generation system, namely the Super NES. Although Nintendo did not discontinue the initial console NES officially, the sales of the old NES were small and could be neglected somewhat.

Hotelling's framework is used to model customers' choices. Customers' ideal points are distributed uniformly in $[a,b]$. Firms position their products on the real line $\Re$, which follows Lilien, et. al (1995), Tabuchi and Thisse (1995), and Tyagi (2000). Customers with ideal point t value a product q using utility function $u(q,t)=R-(q-t)^2$, where R is the reservation price of customers, which is assumed to be the same for all customers and high enough so that all customers buy (Tyagi 2000). Note that in Hotelling's model, a higher value of quality does not imply a better product. Hence more quality does not imply more utility. A quality level simply denotes a position in the market with respect to a set of heterogeneous customers.

When there are two firms in the market and each offers a product with quality q_i at price p_i, $i=1,2$, customers with ideal point t would prefer q_1 to q_2 (assuming $q_1<q_2$) if and only if $R-(t-q_1)^2-p_1 \geq R-(t-q_2)^2-p_2$ which implies $t<\dfrac{p_2-p_1}{2(q_2-q_1)}+\dfrac{q_1+q_2}{2}$. Note that $q_1<t<q_2$.

So those customers whose ideal points are in $[a,t]$ will choose product q_1, and customers whose ideal points are in $[t,b]$ will choose product q_2. The boundary between the markets held by the two firms is at t which is denoted as c_p.

Assumes that customers' ideal points are distributed uniformly in $[-1/2,1/2]$. Also assume $q_{A1}<q_B$ throughout the paper. The analysis for $q_{A1}>q_B$ is symmetric and is not covered here. The whole time horizon is normalized to 1 and the lengths of periods 1 and 2 are denoted by α and β, respectively. The value of α is a decision variable made by firm B; β is fixed, i.e., assume that it takes firm A a fixed amount of time to adjust its position in response to firm B's entry; and the length of period 3 is $1-\alpha-\beta$. Note that $0<\alpha<1$, $0<\beta<1$, and $\alpha+\beta<1$. The analysis is limited to the case when $\alpha+\beta<1$ since otherwise firm A does not get a chance to adjust its position within the time horizon.

At time 0, firm A's unit production cost is c_A, while firm B's unit production cost is c_B, which are determined by the technologies and equipment then required for the firms to produce desired products. Assume the initial investments are exogenous and hence the production costs at time 0 are given. Once the firms enter the market, their production costs will not change. As firm B waits for time period α to enter the market, its production cost changes to $c_B(1-\alpha)$ which is a decreasing function of the decision variable α. The cost reduces because of advances in process technology that firm B is able to enjoy on account of its late entry time. Call c_B the initial production cost and $c_B(1-\alpha)$ the actual production cost of firm B. If firm A adjusts its product design in period 3, it incurs a switching cost $k(q_{A1}-q_{A3})^2$ which is quadratic in the extent of deviation in its product designs from the first period to the third period. This captures the notion that design change is expensive and the cost depends on the extent of change. The parameter k captures the flexibility of firm A in changing its product design. This one-time product and process design related switching cost is independent of production volume.

As in Tyagi (2000), in order to ensure that no firm is so cost disadvantaged that it does not participate, assume $0<c_A<9/5$ and $c_B<\dfrac{9+10c_A+3\sqrt{9-5c_A}}{25\beta}$. These conditions are required in the analysis to get feasible solutions.

Let Π_i^j, $i\in\{A,B\}$, $j\in\{1,2,3\}$ denote firm i's profit in period j; Π_i, $i\in\{A,B\}$ denote firm i's total profit for the planning horizon; And c_p^j, $j\in\{2,3\}$ denote the critical point in period j, which divides the markets held by each firm.

Why would firms in reality act in a myopic way? Hauser, Simester, and Wernefelt (1994) note that ``all employees (managers, product designers, service providers, production workers, etc.) allocate their effort between actions that influence current period sales and actions that influence sales in the future. Unfortunately, employees generally more focus on the short term than the firm would like." Mizik and Jacobson (2007) also provide evidence to show that managers often have incentives to enhance short-term performance to increase firm's short-time stock prices even if they need to sacrifice long-time profits. Hence in this paper it will be interesting to explore the myopic case in which firm A is myopic in period 1 and does not anticipate the entry of the competitor. Firm B also decides its product strategies myopically by maximizing only its second period profit, ignoring the potential response of firm A in the third period.

Next period by period formulations and solutions are provided. Because both firms act myopically, the problem is analyzed starting from period 1 to period 3.

Period 1: Firm can position its product anywhere along the attribute space, cover the whole market and charge a price as high as it can as long as $R-(t-q_{A1})^2-p_{A1}\geq 0$ for all customers. Hence firm A is facing the following problem:

$$\max_{q_{A1},p_{A1}} p_{A1}-c_A$$

$$\text{subject to: } R-p_{A1}-(t-q_{A1})^2\geq 0\ \}\text{ for all } t\in[-1/2,1/2]$$

It is easy to see that firm A reaches its maximal profit when $q_{A1}^{*}=0$ and $p_{A1}^{*}=R-0.25$ and the optimal profit is $\Pi_{A}^{1*}=R-c_{A}-0.25$.

The value of R will affect the magnitude of firm A's optimal profit in this period and thus the total profit over the whole time horizon but will not affect the nature of decisions.

Period 2: The firms' profits, Π_{A}^{2} and Π_{B}^{2}, are now given by equations

$$\Pi_{A}^{2}=(1-\alpha)(p_{A2}-c_{A})(\frac{1}{2}+\frac{p_{B2}-p_{A2}}{2q_{B}}+\frac{q_{B}}{2})$$

$$\Pi_{B}^{2}=(1-\alpha)(p_{B2}-c_{B}(1-\alpha))(\frac{1}{2}-\frac{p_{B2}-p_{A2}}{2q_{B}}-\frac{q_{B}}{2})$$

In other words, firm B maximizes its profit over a time period with length of $(1-\alpha)$ instead of β.

To solve the problem, prices are found first for any given α and q_{B} and after inserting for the optimal prices, α^{*} and q_{B}^{*} are determined. Since Π_{A}^{2} is a concave function of p_{A2} and Π_{B}^{2} is a concave function of p_{B2}, from the first order condition, the prices are

$$p_{A2}^{*}=q_{B}+\frac{1}{3}q_{B}^{2}+\frac{2}{3}c_{A}+\frac{1}{3}c_{B}(1-\alpha) \qquad (3.1)$$

$$p_{B2}^{*}=q_{B}-\frac{1}{3}q_{B}^{2}+\frac{1}{3}c_{A}+\frac{2}{3}c_{B}(1-\alpha) \qquad (3.2)$$

Substitute p_{A2}^{*} and p_{B2}^{*} into Π_{B}^{2}. Differentiating Π_{B}^{2} with respect to q_{B} and α, by the first order conditions,

$$\alpha^{*}=1-\frac{9+10c_{A}-3\sqrt{9-5c_{A}}}{25c_{B}} \qquad (3.3)$$

$$q_{B}^{*}=\frac{3+\sqrt{9+12c_{B}(1-\alpha^{*})-12c_{A}}}{6}=\frac{3+\sqrt{9-5c_{A}}}{5} \qquad (3.4)$$

Following (3.3) and (3.4), the first result is stated as following.

Proposition 1. The higher firm A's cost is, (i) the earlier firm B enters the market; (ii) the closer firm B positions to the most attractive location.

Intuitively, as firm A's cost becomes larger, it is easier for firm B to gain a cost advantage over firm A. Hence it enters earlier. Also it lowers firm B's need to buffer price competition from firm A, which allows it to locate closer to the most attractive location.

Note that firm B's actual production cost $c_{B}(1-\alpha^{*})=\frac{9+10c_{A}-3\sqrt{9-5c_{A}}}{25}$ is independent of c_{B} and is a function of c_{A} only while the timing of its entry is affected by both. Firm B's actual cost needs to be lower than c_{A} regardless the value of initial cost c_{B} to gain a cost advantage over firm A so that firm A's first-mover advantage can be offset. Hence firm B's actual cost only relates to c_{A} but not c_{B}. To have a lower cost, firm B needs to wait for the right entry time. Intuitively, the higher c_{B} is, the longer it waits; the lower c_{A} is, the longer it waits. Hence α relates to both. This independence also explains why q_{B}^{*} is independent of c_{B} -- the influence of both firms' actual costs is captured by c_{A} solely and not the initial cost of firm B.

Proposition 2 below provides some properties of the second period decisions.

Proposition 2. (i) $p^*_{A2} \geq p^*_{B2}$ for all valid c_A, (ii) $c^2_p > 0$ and $\Pi^{2*}_A \geq \Pi^{2*}_B$ if and only if $c_A \leq \frac{27}{16}$.

Firm A's product cost plays an important role in both firms' decisions. In period 2, firm A is always able to charge a higher price than firm B. But this price advantage does not necessarily bring firm A higher market share and profit; Specifically when $c_A > \frac{27}{16}$, firm A has the price advantage but lower market share and lower profit than firm B. However, for most values of c_A ($c_A \leq \frac{27}{16}$) whenever firm A has higher market share it also has higher profit which implies firm A enjoys first mover advantages in this period.

Period 3: In period 3, firm A changes its position which is followed by both firms readjusting their prices simultaneously. Similar to period 2, to solve the problem, prices are found first for any q_{A3} and after substituting for the optimal prices, q^*_{A3} is determined. The first result shows that q^*_B continues to be on the right of q^*_{A3}.

Proposition 3. $q^*_{A3} < q^*_B$ always holds.

Using Proposition 3, the firms' profits, Π^3_A and Π^3_B, are concave functions of p_{A3} and p_{B3} respectively and are given by the following equations:

$$\Pi^3_A = (1-\alpha-\beta)(p_{A3} - c_A)(\frac{1}{2} + \frac{p_{B3} - p_{A3}}{2(q_B - q_{A3})} + \frac{q_{A3} + q_B}{2}) - k(q_{A1} - q_{A3})^2 \qquad (3.5)$$

$$\Pi^3_B = (1-\alpha-\beta)(p_{B3} - c_B(1-\alpha))(\frac{1}{2} - \frac{p_{B3} - p_{A3}}{2(q_B - q_{A3})} - \frac{q_{A3} + q_B}{2}) \qquad (3.6)$$

Again by the first order conditions,

$$p^*_{A3} = \frac{1}{3}(-q^2_{A3} - 3q_{A3} + (q^*_B)^2 + 3q^*_B + 2c_A + c_B(1-\alpha^*)) \qquad (3.7)$$

$$p^*_{B3} = \frac{1}{3}(q^2_{A3} - 3q_{A3} - (q^*_B)^2 + 3q^*_B + c_A + 2c_B(1-\alpha^*)) \qquad (3.8)$$

It is not possible to get a closed form solution for q^*_{A3} by solving firm A's profit function directly. First consider the special case in which there is no switching cost, i.e., $k = 0$. Solving the problem for period 3 with $k = 0$, $\Pi^3_A |_{k=0}$ reaches its maximum at

$$q^{k=0}_{A3} = \frac{-3 + 4s - \sqrt{657 + 120s - 32s^2}}{30} \qquad (3.9)$$

where $s = \sqrt{9 - 5c_A}$ with domain of $[0,3)$. Again, since firm B's actual production cost $c_B(1-\alpha^*)$ is independent of c_B by (3.3), it's not surprising that $q^{k=0}_{A3}$ is independent of c_B. From its derivative with respect to s, it is easy to check that $q^{k=0}_{A3}$ is a decreasing function of c_A. Since $q^{k=0}_{A3} |_{c_A=1.8} = -0.95 \leq q^{k=0}_{A3} \leq q^{k=0}_{A3} |_{c_A=0} = -0.6$, q^*_{A3} is always negative when $k = 0$. Later this fact will be used in comparing both firms' price changes from period 2 to period 3.

Proposition 4. When $k = 0$, (i) $p^*_{A3} \geq p^*_{B3}$ for $c_A \leq 1.76$, (ii) $c^3_p > 0$ and $\Pi^{3*}_A \geq \Pi^{3*}_B$ if and only if $c_A \leq 1.33$.

Proposition 4 shows that when there is no switching cost, $k = 0$, firm A enjoys first-mover advantages most of the time in period 3 as well. Similar to the case of period 2, in period 3 when firm A gets more profit, it has higher market share than firm B. However, when the cost of firm A is high ($1.33 < c_A < 1.76$), then although firm A charges more than firm B, it has lower market share and earns less profit.

Now consider the effect of the positive change-over cost. Let $c = c_A - c_B(1-\alpha)$ denote the difference between the actual costs of firms A and B. Using equation (3.3) and the fact that $c_A \in (0,1.8]$, $c \in [-0.72,0.72]$. Next it will be proven that the optimal product position of firm A in period 3 is always negative for all c and k.

While the total length of the market is 1, the distance between products is more than 0.6. If the two firms were entering simultaneously and had the same cost then the distance between their locations would have been 0.5. This means in this myopic sequential entry case both firms like to have well differentiated products to alleviate competition.

To provide additional insights, the third period problem is numerically solved for various values of problem parameters, k and c_A. The effects of c_A are summarized in figures 2-1, 2-2 and 2-3 (Appendix) and those of k are summarized in figures 2-4, 2-5 and 2-6 (Appendix).

For fixed k, as c_A gets larger, q^*_{A3} moves away from the center of the market to the left and the difference between q^*_B and q^*_{A3} gets larger (figure 2-1). Higher production cost forces greater product differentiation in order to be more competitive. As shown in equation (3.4), q^*_B is a decreasing function of c_A, thus as c_A changes q^*_{A3} and q^*_B are not symmetric around 0. As c_A increases, as expected, firm A's market share decreases, so does its profit. Firm B's market share and profit have opposite tendencies compared to firm A's due to the cost advantage firm B gets as the cost of firm A increases. For most feasible values of c_A, firm A's market share and profit are higher than firm B's. But when c_A gets very large, firm B dominates in market share and its total profit is also higher (figures 2-2 and 2-3). So in general, firm A enjoys first mover advantages except when its production cost is very high.

Recall that firm A has less flexibility as k increases. In figure 2-4, as k increases, q^*_{A3} moves closer to the center of the market -- its position in period 1. Lower flexibility prevents firm A from making large adjustment in product design in period 3. Since q^*_{A3} increases with k and q^*_B is independent of k, the positions of q^*_{A3} and q^*_B are normally not symmetric around the center of the market when the production costs are fixed. This supports a similar result in Götz (2005).

Now check how each firms' prices change from period 2 to period 3. Using equations (3.1) and (3.2), the price change for firm A is $p^*_{A3} - p^*_{A2} = q^{*2}_{A3}/3 - q^*_{A3}$. Hence p^*_{A3} is greater than p^*_{A2} as long as $q^*_{A3} \in [-3,0]$. Similarly $p^*_{B3} > p^*_{B2}$ always holds. Hence both firms are able to increase their prices in period 3 from period 2. In period 3, firm A is pulling back thus the product differentiation is increasing. This diminishes the competition for some customers, allowing the firms to charge higher prices.

Now Let's analyze the relationship between p_{A3}^* and p_{B3}^* for $k>0$. It is interesting to know when is the price charged by firm A higher than the price changed by firm B. To find this, look at $p_{A3}^* - p_{B3}^* > 0$ and obtain:

$$-\frac{\sqrt{27+5c_A+9\sqrt{9-5c_A}}}{5\sqrt{2}} < q_{A3}^* < \frac{\sqrt{27+5c_A+9\sqrt{9-5c_A}}}{5\sqrt{2}}$$

Using the facts that $q_{A3}^* < 0$ and $c_A \in (0,1.8]$ the above inequalities imply that for $p_{A3}^* > p_{B3}^*$ to hold $-1.04 < q_{A3}^* < 0$ should be true. From figure 2-4, p_{A3}^* is greater than p_{B3}^* within the range of parameters' values that are studied.

Although firm A's market share is lower in period 3 than in period 2, higher price allows it to earn more profit per unit time in period 3 than in period 2. For example, consider the case when $\beta = 0.3, c_A = 1.5, c_B = 1.8, k = 0.3$. Although $c_p^3 = 0.046$ is smaller than $c_p^2 = 0.063$, $p_{A3}^* = 2.63$ is higher than $p_{A2}^* = 2.45$ and $\Pi_A^{3*}/(1-\alpha-\beta) = 0.58$ is more than $\Pi_A^{2*}/\beta = 0.54$.

As shown in figures 2-5 and 2-6, as firm A's flexibility increases (k decreases), it earns higher profit but has lower market share. Firm A enjoys first mover advantages except when its flexibility is very high. Both firms benefit from firm A's flexibility, but firm B benefits more since its profit increases faster. As its flexibility increases, market share is the price that firm A pays for higher profit. The profit of firm A is not always higher than that of firm B, as the graph II in figure 2-6 for case ($\beta = 0.3, c_A = 1.8, c_B = 1.4$) shows. When flexibility is very high firm A may lose its first mover advantages.

4 CONCLUSION

This paper considered two myopic firms who enter a market sequentially and compete on product positions and prices. A three-period game-theoretical model is developed to explore the product introduction decisions of entry timing, designs, and prices, and to investigate the effects of product flexibility and production cost on first-mover advantages. Analytical results for optimal product and pricing strategies are provided.

The paper showed that the pioneer generally enjoys first-mover advantages in terms of achieving higher prices, higher market shares, and higher profits. But when the late entrant has a superior cost structure, these advantages are offset. The late entrant waits until it obtains a low cost. The pioneer's product flexibility allows it to adjust its product strategies in response to the late entrant's entry. This research showed that as the process becomes more flexible, both firms benefit, but higher flexibility is even better for the late entrant than for the pioneer.

The results showed that generally the positions of products by the two competitors are not symmetric. As the first mover's production cost gets larger, it moves further from, and the late entrant moves toward, the center of the market. When both firms have full knowledge of each other's move, the late entrant will enter the market earlier; The pioneering company will position its product away from the most desirable position of the market; The pioneer's position will also be further from the center of the market, compared to the myopic case.

This research can be extended in many ways. The use of more realistic nonlinear production costs should improve the usefulness of this work, as will giving the first mover freedom to time its adjustment to its product strategies after the competitor enters the market. It will be interesting to study the non-myopic case: when both firms have full knowledge of each other's move how the strategies and decisions are different from myopic case.

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APPENDIX

1. Figure 1

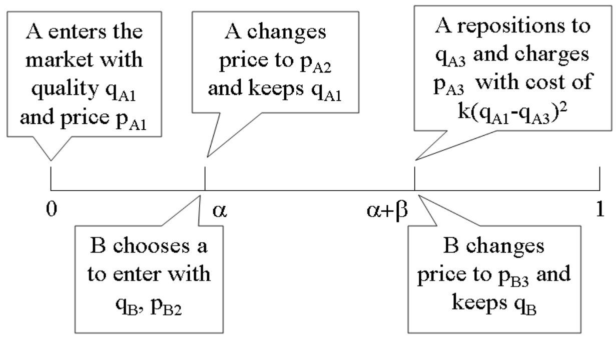

Figure 1: Timeline of events

2. Figure 2

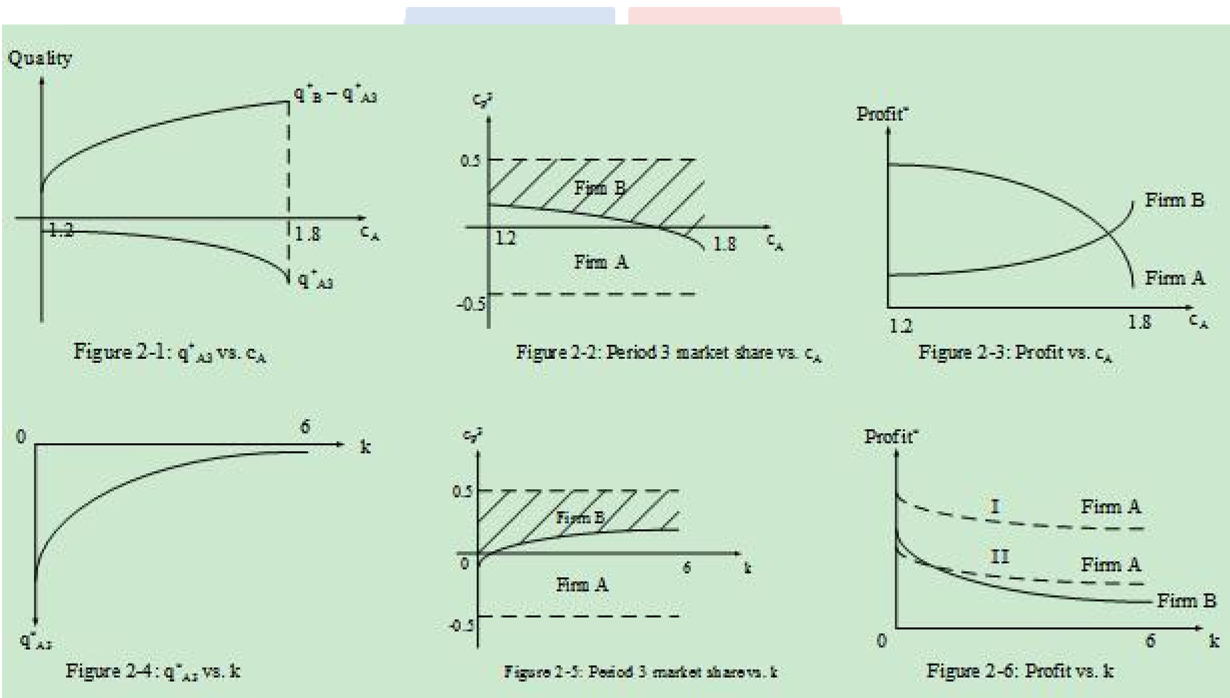

Figure 2-1: q^*_{A3} vs. c_A

Figure 2-2: Period 3 market share vs. c_A

Figure 2-3: Profit vs. c_A

Figure 2-4: q^*_{A3} vs. k

Figure 2-5: Period 3 market share vs. k

Figure 2-6: Profit vs. k

* The profit is the firm's total profit over all period.

3. Proof of Proposition 2

(i) Note that $p^*_{A2} - p^*_{B2} = \dfrac{27 + 5c_A + 9\sqrt{9 - 5c_A}}{75}$. Hence $p^*_{A2} - p^*_{B2} \geq 0$ is equivalent to $-27 \leq c_A \leq 9/5$, which always holds.

(ii) $c_p^2 = \frac{p_{B2}^* - p_{A2}^*}{2q_B^*} + \frac{q_B^*}{2} = \frac{27 - 20c_A + 9\sqrt{9 - 5c_A}}{30(3 + \sqrt{9 - 5c_A})}$. Hence $c_p^2 \geq 0$ is equivalent to $c_A \leq \frac{27}{16}$.

The difference between the profits of the two firms in period 2 is a one-variable function of c_A and is given by $\frac{\Pi_A^{2*} - \Pi_B^{2*}}{\beta} = \frac{54 - 40c_A + 18\sqrt{9 - 5c_A}}{75}$. It is easy to verify that $\Pi_A^{2*} - \Pi_B^{2*} \geq 0$ is equivalent to $c_A \leq \frac{27}{16}$.

4. Proof of Proposition 3

If q_{A3} is greater than q_B, denote the corresponding prices by $p_{A3}^{'}$ and $p_{B3}^{'}$ as well as firms' profits in period 3 by $\Pi_A^{3'}$ and $\Pi_B^{3'}$. Similar to the case that q_{A3} is smaller than q_B,

$$\Pi_A^{3'} = \frac{1}{2}(1 - \alpha - \beta)(p_{A3}^{'} - c_A)(1 - \frac{p_{B3}^{'} - p_{A3}^{'}}{q_B - q_{A3}} - q_{A3} - q_B) - kq_{A3}^2$$

$$p_{A3}^{'} = \frac{1}{3}(-q_{A3}^2 + q_B^2 + 3q_{A3} - 3q_B + 2c_A + c_B - c_B\alpha)$$

$$p_{B3}^{'} = \frac{1}{3}(q_{A3}^2 - q_B^2 + 3q_{A3} - 3q_B + c_A + 2c_B - 2c_B\alpha)$$

Need to show that

$$\Pi_A^3 \geq \Pi_A^{3'} \qquad (3.10)$$

It suffices to show that for any fixed $q_{A3}^{'} > q_B$, (3.10) holds for some q_{A3} such that $q_{A3} < q_B$.

Note that $p_{A3} - c_A = (q_B - q_{A3})(1 + \frac{p_{B3} - p_{A3}}{q_B - q_{A3}} + q_B + q_{A3})$. Similarly $p_{A3}^{'} - c_A =$ $(q_{A3}^{'} - q_B)(1 - \frac{p_{B3} - p_{A3}^{'}}{q_B - q_{A3}^{'}} - q_B - q_{A3}^{'})$.

For any fixed $q_{A3}^{'} > q_B$, there always exists a symmetric point of $q_{A3}^{'}$ with respect to q_B. Take this point to be q_{A3}, then $q_B - q_{A3} = q_{A3}^{'} - q_B$ by the choice of q_{A3}. Note that $-k(q_{A1} - q_{A3})^2 \geq -k(q_{A1} - q_{A3}^{'})^2$. Hence by (3.10), it suffices to show that

$$\frac{(p_{A3} - c_A)^2}{q_B - q_{A3}} \geq \frac{(p_{A3}^{'} - c_A)^2}{q_{A3}^{'} - q_B} \qquad (3.11)$$

for some $q_{A3} < q_B$. Then

$$p_{A3} - c_A = (q_{A3}^{'} - q_B)(1 - \frac{q_{A3}^{'}}{3} + q_B - \frac{c}{3(q_{A3}^{'} - q_B)})$$

$$\geq (q_{A3}^{'} - q_B)(1 - \frac{q_{A3}^{'} + q_B}{3} - \frac{c}{3(q_{A3}^{'} - q_B)}) = p_{A3}^{'} - c_A.$$

(3.11) follows.

5. Proof of Proposition 4

The difference between p_{A3}^* and p_{B3}^* is $\frac{-9+87s-s^2+(4s-3)\sqrt{657+120s-32s^2}}{675}$, which is a decreasing function of c_A when $c_A \in (0,1.8]$ and it reaches zero at $c_A = 1.76$.

Similarly $c_p^3 = \frac{p_{B3}^* - p_{A3}^*}{q_B^* - q_{A3}^*} + \frac{q_B^* + q_{A3}^*}{2} \geq 0$ that is equivalent to $c_A \leq 1.33$.

$\frac{\Pi_A^3 - \Pi_B^3}{1-\alpha^* - \beta} = \frac{-585+55s^2+15(41-2s^2)s+(23s-43+3s^2)\sqrt{657+120s-32s^2}}{3375}$, which is also a decreasing function of c_A when $c_A \in (0,1.8]$ and reaches zero at $c_A = 1.33$.