經營科學
第33卷 第4號
2016年 12月, pp.65-75
https://doi.org/10.7737/KMSR.2016.33.4.065

비대칭적 정보 하에서 진입 억제와 가격 경쟁

맹주열[1] · 최성용[2†]
[1]퍼시픽 루터대 경영대학, [2]연세대학교 경영학부

Entry Deterrence and Price Competition under Asymmetric Information

Jooyol Maeng[1] · Sungyong Choi[2†]
[1]School of Business, Pacific Lutheran University
[2]Division of Business Administration, Yonsei University

■ Abstract ■

We study limit pricing in a price-based duopoly market under asymmetric information on the demand state. An incumbent, who is a monopolist in the initial period, has complete information on the size of a market, while a potential entrant only knows it partially. After observing the sales price of the incumbent in the first period, the entrant decides whether to enter a duopoly market and the sales price if she chooses to. We present a separating perfect Bayesian equilibrium, which indicates that limit pricing can deter the entry of a potential entrant under price competition when there is information asymmetry about the demand state.

Keywords : Price-Based Duopoly Market, Limit Pricing, Asymmetric Information, Signaling Game (Production and Operations Management)

논문접수일 : 2016년 09월 09일 논문게재확정일 : 2016년 12월 14일
논문수정일 : 2016년 12월 12일
† 교신저자, sungyong.choi@yonsei.ac.kr

1. Introduction

An incumbent (he) in a marketplace has an incentive to deter entry of a potential rival. He can use a number of entry-deterrence mechanisms, including excess capacity, research and development (R&D) investment, increased advertising, product variety, and limit pricing [16]. The focus of this paper is to study *limit pricing*, the practice whereby an incumbent brings down a price before any potential entry occurs. By charging a price below the myopic profit-maximizing level, the incumbent tries to influence a potential entrant's (she) expectation of post-entry profits. If entry is successfully deterred, the incumbent maintains a long-run monopoly position in the market in return for short-run profit loss. An excellent example of limit pricing can be found in the work of Goolsbee and Syverson [7] on an incident in 2004 involving Southwest Airlines. When this low-cost carrier operated at airports in both Jacksonville and Philadelphia but did not operate the route between them, it was construed as an entry threat by dominant airlines, and these incumbents reduced airfares on this route drastically, by nearly 20%. Seamans [15] also shows evidence for limit pricing in the U.S. cable industry, when entrants serving a region are seen as entry threats by incumbents that are operating in adjacent areas.

We study limit pricing in a two-period Bertrand duopoly market where both an incumbent and a potential entrant sell a single product and the size of the market potential is asymmetric information. It is typical for an incumbent to have an advantage in brand identity, accumulated knowledge about the market, network externalities, investments in technology, or trade relationships, all of which create asymmetries in competing with new entrants [3, 9]. We assume that the size of the market potential is a binary random variable that is common knowledge to both the incumbent and the potential entrant, and only the incumbent knows the true demand state. We model this problem as a two-period signaling game, where the incumbent with private information about the size of the market potential moves first [6, 19]. The entrant observes the sales price set by the incumbent in the first period, but not the type of the demand state he experiences. We analyze a separating perfect Bayesian equilibrium, where each type of the demand state faced by the incumbent is revealed to the entrant through his distinct actions. In this paper, we examine the following research questions: 1) How does the potential entry of an entrant impact the incumbent's price? 2) Does limit pricing exist under price competition when there is asymmetric information on the size of market potential? More specifically, is there a separating perfect Bayesian equilibrium solution?

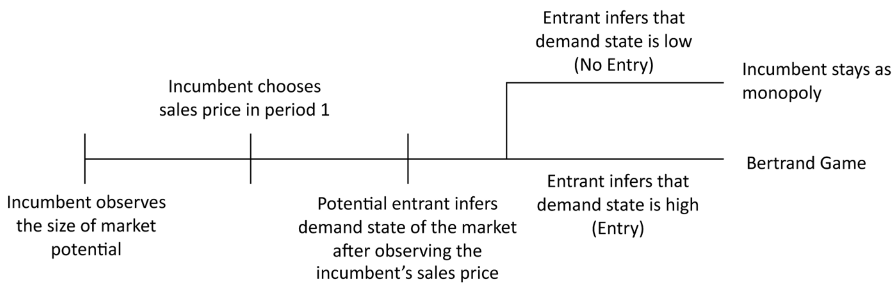
This paper contributes to the literature on entry deterrence. Spence [17, 18] and Dixit [4, 5] study the role of excess capacity and capital investment for entry prevention. Hong [8] shows R&D performance of a manufacturing firm is positively related to Total Quality Management practices, and Karaer and Erhun [10] show that the quality of a product is a deterrent facing a potential entrant. Schmalensee [13] demonstrates product proliferation as a tool of entry deterrence, using as an illustration the U.S. ready-to-eat breakfast-cereal industry. Offering product variety through new product introduction not only increases the market share of a company [11] but also works as an entry-deterrence mechanism. Schmalensee [14] further analyzes advertising as an effective strategy to deter entry. The use of sales price as an entry-deterrence tool is introduced by Bain [1], and the effectiveness of this strategy is shown in Milgrom and Roberts [12]. They show that when the incumbent's production cost is asymmetric information to a potential entrant, the incumbent's lowering his sales price signals a low production cost, thereby deterring her entry. Our paper is similar to Milgrom and Roberts [12], in that we study limit pricing as a strategy to deter the entry of a potential entrant. However, our focus is on asymmetric information on market potential, as described in Besanko [3]. Furthermore, we consider the Bertrand duopoly model, where firms compete in price, whereas Milgrom and Roberts [12] analyze the Cournot duopoly model, where firms compete in production quantity. We demonstrate that limit pricing is an effective mechanism for entry deterrence when the size of the market potential is asymmetric information.

The remainder of this paper is organized as follows. The formulation of the model is described in §2. Section 3 analyzes a separating equilibrium in this signaling game of limit pricing. Section 4 shows a numerical example of limit-pricing equilibrium solutions based on results in §3, and our concluding remarks follow in §5.

2. Model Framework

We consider a two-period duopoly signaling game, where both firms - an incumbent (he) and a potential entrant (she) - produce homogeneous goods of equal quality. The sequence of events is as follows (see <Figure 1>). The incumbent, who is a monopolist in the initial period, fully observes the size of market potential and chooses a sales price that maximizes his profit. The potential entrant, who has partial information on the market, observes the sales price of the incumbent and infers the size of the market potential. Then she decides whether to enter the market in the second period. If the potential entrant enters, the situation becomes a Bertrand duopoly competition in the second period; otherwise, the incumbent remains a monopolist in the market.

In this paper, we assume that both firms sell a homogeneous product and have the same production costs. Due to the advantages of incumbency mentioned in §1, it is very likely that the incumbent's product is of higher quality and cheaper than the entrant's. As Balasubramanian and Bhardwaj [2] note, "endowing the firms with identical own and cross effects in the context of price and quality places the firms on an equal competitive footing." This assumption of a homogeneous product and identical cost allows us to focus on limit pricing under conditions of asymmetric information without delving into the detailed characteristics of firms or products.



〈Figure 1〉 Sequence of Events

Let D_j be the demand of the product experienced by firm j, where j is either the incumbent (with the subscript i) or the entrant (with the subscript e). We use a Bertrand-type linear demand function that decreases in its own price and increases in the competitor's price as in equations (1) and (2). The underlying demand of the product sold by each firm, $\tilde{A}$, is a random variable taking a *high* value A_H with probability β and a *low* value A_L with probability $1-\beta$, where $0 \le \beta \le 1$ and $A_H \ge A_L$. A_H and A_L correspond to high and low demand states respectively, and the ratio between A_H and A_L is given as α, where $\alpha = A_H/A_L$. The distribution of $\tilde{A}$ is common knowledge to both firms, but only the incumbent has perfect information on market demand, creating an information asymmetry between the two players. The firm j chooses sales price p_j per item, which is the action in this duopoly price competition. We assume γ, the sensitivity of demand to the competing product's price, is between 0 and 1, i.e., $\gamma \in (0, 1)$

$$D_i(p_i, p_e) = \tilde{A} - p_i + \gamma \cdot p_e \quad (1)$$

$$D_e(p_i, p_e) = \tilde{A} - p_e + \gamma \cdot p_i \quad (2)$$

Let c be the acquisition cost from the supplier, which is the same for both firms. We assume that information regarding the sensitivity of demand γ and acquisition cost c is common knowledge. Then the profit function of the incumbent, Π_i, is determined by the contribution margin multiplied by demand experienced when p_i and p_e are chosen as shown in equation (3). We assume that the entrant incurs fixed cost K if she enters the market in the second period. Therefore, the profit function of the entrant, Π_e, can be represented as in the equation (4). We do not consider the time value of money in this model.

$$\Pi_i(p_i, p_e) = (p_i - c) \cdot D_i(p_i, p_e) \quad (3)$$

$$\Pi_e(p_i, p_e) = (p_e - c) \cdot D_e(p_i, p_e) - K \quad (4)$$

As the first step in solving this two-period game, we need to consider two base scenarios, namely a monopoly market and a duopoly market under perfect information. In the following two lemmas, we find the profit-maximizing sales price of the incumbent under a monopoly market and equilibrium outcomes for the single-period simultaneous move game under perfect information.

Lemma 1. *In a monopoly market, the profit-maximizing incumbent chooses the following outcomes in terms of sales price* (p_i^M) and profit (Π_i^M).

$$p_i^M = \frac{\tilde{A} + (1-\gamma)c}{2(1-\gamma)} \quad (5)$$

$$\Pi_i^M = \frac{(1+\gamma)\{\tilde{A} - (1-\gamma)c\}^2}{4(1-\gamma)} \quad (6)$$

Proof. Rearranging terms in equations (1) and (2), the price function in terms of demands of both firms becomes

$$p_i = \frac{1}{1-\gamma}\tilde{A} - \frac{1}{1-\gamma^2}D_i - \frac{\gamma}{1-\gamma^2}D_e \quad (7)$$

Setting $D_e = 0$ in equation (7) and rearranging terms, we get $D_i = (1+\gamma)\tilde{A} - (1-\gamma^2)p_i$. The solution to the first order condition after inserting D_i into equation (3) gives $p_i^M = \frac{\tilde{A} + (1-\gamma)c}{2(1-\gamma)}$. By substituting $D_i = (1+\gamma)\tilde{A} - (1-\gamma^2)p_i^M$ and equation (5) into equation (3), we get Π_i^M in equation (6). □

Lemma 2. *In a simultaneous move game with complete information, the incumbent and the* *entrant have the following subgame-perfect Nash equilibrium in terms of sales prices* (p_j^*) *and profits* (Π_j^*).

$$p_i^* = p_e^* = \frac{\tilde{A}+c}{2-\gamma} \quad (8)$$

$$\Pi_i^* = \Pi_e^* = \frac{\{\tilde{A}-(1-\gamma)c\}^2}{(2-\gamma)^2} \quad (9)$$

Proof. Both firms solve the following profit functions, and the solution to the first-order conditions give the results.

$$\Pi_i^*(p_i, p_e) = \max_{p_i} (p_i - c)\cdot(\tilde{A} - p_i + \gamma\cdot p_e)$$

$$\Pi_e^*(p_i, p_e) = \max_{p_e} (p_e - c)\cdot(\tilde{A} - p_e + \gamma\cdot p_i) - K \quad \square$$

To avoid trivial cases, we assume that the entrant's profit is positive when the underlying demand is high and negative when it is low, i.e., $\frac{\{A_L-(1-\gamma)c\}^2}{(2-\gamma)^2} < K < \frac{\{A_H-(1-\gamma)c\}^2}{(2-\gamma)^2}$. In other words, the entrant has an incentive to enter the duopoly market only if the demand state is high.

3. Separating Equilibrium

In this section, we analyze a separating perfect Bayesian equilibrium for this signaling game. Under this equilibrium, each type of leader (incumbent) chooses a different action, revealing his type to a follower (entrant). In other words, an incumbent of a given type *separates* himself from the other types by choosing a unique action that no other incumbent chooses. Throughout the paper, we refer to the incumbent experiencing the high demand state as the *high-type* incumbent and the one experiencing the low demand state as the *low-type* incumbent.

Let $p_i^{t\theta}$ denote the sales price set by the incumbent of type θ in period t where $t \in \{1, 2\}$ and $\theta \in \{H, L\}$ where H and L refer to high and low demand states respectively, and let p_e^2 represent the sales price of the entrant in period 2. Let $\mu(p_i^{1\theta})$ be the entrant's belief that the incumbent is the high type after observing his pre-entry price $p_i^{1\theta}$, i.e., $\mu(p_i^{1\theta}) = Pr\{\tilde{A} = A_H \mid p_i^{1\theta}\}$. Without loss of generality, we normalize c to zero.

To find an equilibrium solution, we need to identify a profile of strategies $\{p_i^{1L}, p_i^{1H}, p_i^{2L}, p_i^{2H}, p_e^2(p_i^{1\theta})\}$ and the entrant's belief $\mu(p_i^{1\theta})$. As a first step, we solve the second-period problem when the incumbent's type is revealed to the entrant through his action in the first period.

Lemma 3. (a) *In a separating equilibrium, when the entrant believes that* $\tilde{A} = A_L$, *she stays out, and the incumbent chooses* $p_i^{2L} = \frac{A_L}{2(1-\gamma)}$.

(b) *If the entrant believes that* $\tilde{A} = A_H$, *she enters the duopoly competition and both firms choose* $p_i^{2H} = p_e^2 = \frac{A_H}{2-\gamma}$

Proof. (a) If the entrant believes the incumbent is the low type, she is better off not entering the market in the second period because her revenue is less than the fixed cost, i.e., $\frac{A_L^2}{(2-\gamma)^2} < K$. Knowing that the entrant does not enter the market in the second period, the incumbent chooses the sales price that maximizes his profit under monopoly as given in equation (5).

(b) On the other hand, if the entrant believes that the incumbent is the high type, she can earn positive profit of $\frac{A_H^2}{(2-\gamma)^2} - K$ by choosing $p_e^2 = \frac{A_H}{2-\gamma}$ after entering the duopoly price competition. Then the high-type incumbent chooses an equilibrium price $p_i^{2H} = \frac{A_H}{2-\gamma}$ from equation (8). □

After an incumbent's type is revealed through his action in period 1, Lemma 3 describes the actions of the entrant and both types of incumbent in period 2. If the incumbent is the low type, the entrant does not enter in the second period, and the incumbent keeps the monopoly profit. On the other hand, if he is the high type, each firm chooses the price that maximizes his/her profit in the duopoly competition.

The following lemma shows the pre-entry price set by the low-type incumbent in period 1. Whether or not the entrant enters the market in the second period, the low-type incumbent's monopoly price maximizes his profit for two entire periods.

Lemma 4. *In a separating equilibrium, the low-type incumbent chooses the following sales price in period 1.*

$$p_i^{1L} = \frac{A_L}{2(1-\gamma)}$$

Proof. Suppose the incumbent deviates to $\widehat{p_i^{1L}} \neq \frac{A_L}{2(1-\gamma)}$ and thus $\Pi_i^M(\widehat{p_i^{1L}}) < \Pi_i^M$. If the entrant believes $P(\widetilde{A} = A_L \mid \widehat{p_i^{1L}}) = 1$, she does not enter in the second period, and the incumbent remains a monopolist. In this case, the monopoly profit in the second period should satisfy the following condition: $\Pi_i^M(p_i^2) \geq 2\Pi_i^M - \Pi_i^M(\widehat{p_i^{1L}})$. That is, the monopoly profit in the second period should make up the profit loss from choosing $\widehat{p_i^{1L}}$. However, according to Lemma 1, we have $\Pi_i^M \geq \Pi_i^M(p_i^2) \geq 2\Pi_i^M - \Pi_i^M(\widehat{p_i^{1L}})$ or equivalently, $\Pi_i^M(\widehat{p_i^{1L}}) \geq \Pi_i^M$. Contradiction occurs. On the other hand, if the entrant believes $P(\widetilde{A} = A_L | \widehat{p_i^{1L}}) < 1$, she may enter the duopoly market in the second period. Using a similar argument, the duopoly profit of the incumbent in the second period should satisfy the following condition: $\Pi_i(p_i^2,\ p_e^2) \geq \Pi_i^M + \Pi_i^* - \Pi_i^M(\widehat{p_i^{1L}})$. From Lemma 1, we have $\Pi_i^* \geq \Pi_i(p_i^2,\ p_e^2) \geq \Pi_i^M + \Pi_i^* - \Pi_i^M(\widehat{p_i^{1L}})$ or equivalently, $\Pi_i^M(\widehat{p_i^{1L}}) \geq \Pi_i^M$. Contradiction occurs. Therefore, we conclude $p_i^{1L} = \frac{A_L}{2(1-\gamma)}$. □

To provide complete solutions to the equilibrium, we need to set *off-the-equilibrium-path* decisions to prevent an incumbent from choosing p_i^1 that is neither p_i^{1L} nor p_i^{1H}. We can discourage such action by assigning the belief of the entrant in a way that makes the strategy unattractive to the incumbent. The incumbent's profit decreases when the entrant enters the duopoly market. Therefore, we set the belief of the entrant that the incumbent is the high type whenever p_i^1 deviates from p_i^{1L}. Then the off-the-equilibrium-path beliefs can be represented as follows:

$$\mu(p_i^1) = \begin{cases} 0 & if\ p_i^1 = p_i^{1L} \\ 1 & if\ p_i^1 \neq p_i^{1L} \end{cases} \tag{10}$$

Combined with Lemma 3, this belief makes the entrant enter the market in the second period if $p_i^1 \neq p_i^{1L}$. Otherwise, she stays out.

It is possible for an incumbent of a given type to mimic the price decision of the other type. For example, the high-type incumbent can set the price low in the first period and trick the entrant into not entering competition in the second period. Therefore, we need to set a range of p_i^{1H} that meets *incentive compatibility constraints* of sticking to its own type, and this is stated in the subsequent proposition.

Proposition 5. *For the high-type incumbent not to deviate,* p_i^{1H} *must satisfy one of the following conditions.*

$$p_i^{1H} \le \frac{A_H}{2(1-\gamma)}\left\{1-\sqrt{\frac{\gamma(\gamma^2-3\gamma+4)}{(1+\gamma)(2-\gamma)^2}}\right\} \quad (11)$$

$$or \;\; p_i^{1H} \ge \frac{A_H}{2(1-\gamma)}\left\{1+\sqrt{\frac{\gamma(\gamma^2-3\gamma+4)}{(1+\gamma)(2-\gamma)^2}}\right\}$$

Proof. We need to make sure the high-type incumbent makes less profits when it mimics the low-type incumbent. Mathematically, it can be expressed in the following inequality.

$$p_i^{1H}\{(1+\gamma)A_H-(1-\gamma^2)p_i^{1H})\}+\frac{(1+\gamma)A_H^2}{4(1-\gamma)} \le \frac{(1+\gamma)A_H^2}{4(1-\gamma)}+\frac{A_H^2}{(2-\gamma)^2}$$

The terms on the right-hand side are the monopoly profit in the first period when the demand state is high followed by the profit under the duopoly competition in the second period. The sum of these terms should be greater than or equal to the profit of the high-type incumbent mimicking the low type followed by the monopoly profit when the entrant is scared off in the second period. Rearranging the terms, we get

$$(1-\gamma^2)(p_i^{1H})^2-(1+\gamma)A_H\, p_i^{1H}+\frac{(A_H)^2}{(2-\gamma)^2} \ge 0$$

Since $\gamma \in (0, 1)$ $1-\gamma^2$ is positive. Using the quadratic formula, two roots of the quadratic equation become

$$p_i^{1H}=\frac{(1+\gamma)A_H \pm \sqrt{\frac{\gamma(1+\gamma)(\gamma^2-3\gamma+4)}{(2-\gamma)^2}(A_H)^2}}{2(1-\gamma^2)}$$

$$=\frac{A_H}{2(1-\gamma)}\left\{1 \pm \sqrt{\frac{\gamma(\gamma^2-3\gamma+4)}{(1+\gamma)(2-\gamma)^2}}\right\}$$

Therefore, the incentive compatibility constraints of the high-type incumbent satisfy either $p_i^{1H} \le \frac{A_H}{2(1-\gamma)}\left\{1-\frac{\sqrt{\gamma(\gamma^2-3\gamma+4)}}{(1+\gamma)(2-\gamma)^2}\right\}$ or $p_i^{1H} \ge \frac{A_H}{2(1-\gamma)}\left\{1+\sqrt{\frac{\gamma(\gamma^2-3\gamma+4)}{(1+\gamma)(2-\gamma)^2}}\right\}$. □

Similarly, we need to make sure that the low-type incumbent does not have an incentive to mimic the action of the high type. The following proposition shows the range of p_i^{1H} that meets incentive compatibility constraints of the low-type incumbent.

Proposition 6. *When* $\alpha \le \frac{2-\gamma}{\gamma}\left(\sqrt{\frac{1+\gamma}{1-\gamma}}-1\right)$*, the low-type incumbent has an incentive not to deviate, and* p_i^{1H} *must satisfy the following condition.*

$$\frac{A_L}{2(1-\gamma)}\left\{1-\sqrt{1-\frac{(1-\gamma)(2-\gamma+\gamma\alpha)^2}{(1+\gamma)(2-\gamma)^2}}\right\} \quad (12)$$

$$\le p_i^{1H} \le \frac{A_L}{2(1-\gamma)}\left\{1+\sqrt{1-\frac{(1-\gamma)(2-\gamma+\gamma\alpha)^2}{(1+\gamma)(2-\gamma)^2}}\right\}$$

Proof. To make sure that the low-type incumbent does not want to deviate to p_i^{1H}, the following inequality must hold.

$$p_i^{1H}\{(1+\gamma)A_L-(1-\gamma^2)p_i^{1H}\}+\frac{(1+\gamma)A_L^2}{4(1-\gamma)}$$

$$\ge \max_{p_i^1} p_i^1\{(1+\gamma)A_L-(1-\gamma^2)p_i^1\}$$

$$+\max_{p_i^2} p_i^2\left(A_L-p_i^2+\gamma\cdot\frac{A_H}{2-\gamma}\right)$$

Terms on the left-hand side of the inequality are the low-type incumbent's monopoly profit in the first period followed by the incumbent's profit when the entrant, believing he is the low type, does not enter in the second period. These terms should be greater than the maximum profit of the low-type incumbent deviating to the high type. Given the belief system that the entrant enters when the market has experienced high demand state, the second term on the right-hand side of the inequality represents the incumbent's maximum profit in the duopoly market when the entrant sets the price of $\frac{A_H}{2-\gamma}$ in the second period. The first term is the maximum monopoly profit the high-type incumbent can generate in the first period.

Rearranging the terms we get the following inequality.

$$(1-\gamma^2)(P_i^{1H})^2-(1+\gamma)A_L P_i^{1H}+\frac{((2-\gamma)A_L+\gamma A_H)^2}{4(2-\gamma)^2}\le 0 \quad (13)$$

Using the relation $A_H=\alpha A_L$, two roots of the quadratic equality become

$$P_i^{1H}=\frac{A_L}{2(1-\gamma)}\left\{1\pm\sqrt{1-\frac{(1-\gamma)(2-\gamma+\gamma\alpha)^2}{(1+\gamma)(2-\gamma)^2}}\right\} \quad (14)$$

For P_i^{1H} to exist, the term inside the square root in equation (14) must be non-negative, i.e., $1-\frac{(1-\gamma)(2-\gamma+\gamma\alpha)^2}{(1+\gamma)(2-\gamma)^2}\ge 0$. Otherwise, there is no P_i^{1H} that satisfies the quadratic inequality (13). Rearranging the term with respect to α, we get $\alpha\le\frac{2-\gamma}{\gamma}\left(\sqrt{\frac{1+\gamma}{1-\gamma}}-1\right)$. Finally, the range of P_i^{1H} in inequality (12) satisfies the inequality (13).

Proposition 6 states that there is a range of α with respect to γ that ensures the incentive compatibility of the low-type incumbent. When both conditions in Propositions 6 and 7 are satisfied, the range of p_i^{1H} is determined. Combining all previous results, we get the following separating perfect Bayesian equilibrium outcomes $\{p_i^{1L}, p_i^{1H}, p_i^{2L}, p_i^{2H}, p_e^2(p_i^{1\theta}), \mu(p_i^{1\theta})\}$ for this two-stage signaling game.

Theorem 7. *There is a continuum of a separating perfect Bayesian equilibrium when* $\alpha\le\frac{2-\gamma}{\gamma}\left(\sqrt{\frac{1+\gamma}{1-\gamma}}-1\right)$, *and they satisfy the following conditions.*

(a) $\underline{P_L}\le p_i^{1H}\le\min\{\overline{P_L},\ \underline{P_H}\}$,

(b) $p_i^{1H}=\overline{p_H}\cdot 1_{\{\alpha=1\}}$,

(c) $p_i^{1L}=\frac{A_L}{2(1-\gamma)}$,

(d) $p_i^{2L}=\frac{A_L}{2(1-\gamma)}$,

(e) $p_i^{2H}=\frac{A_H}{2-\gamma}$,

(f) $\mu(p_i^1)=\begin{cases}0 & if\ p_i^1=p_i^{1L}\\ 1 & if\ p_i^1\ne p_i^{1L}\end{cases}$, *and*

(g)[1]

$$p_e^2(p_i^1)=\begin{cases}\frac{(2-\gamma)A_L}{2(1-\gamma)} & if\ p_i^1=p_i^{1L}\\ \frac{A_H}{2-\gamma} & if\ p_i^1\ne p_i^{1L}\end{cases}$$

where $\underline{p_L}=\frac{A_L}{2(1-\gamma)}\left\{1-\sqrt{1-\frac{(1-\gamma)(2-\gamma+\gamma\alpha)^2}{(1+\gamma)(2-\gamma)^2}}\right\}$,

$$\overline{p_L}=\frac{A_L}{2(1-\gamma)}\left\{1+\sqrt{1-\frac{(1-\gamma)(2-\gamma+\gamma\alpha)^2}{(1+\gamma)(2-\gamma)^2}}\right\},$$

$$\underline{p_H}=\frac{A_H}{2(1-\gamma)}\left\{1-\sqrt{\frac{\gamma(\gamma^2-3\gamma+4)}{(1+\gamma)(2-\gamma)^2}}\right\},$$

$$\overline{p_H}=\frac{A_H}{2(1-\gamma)}\left\{1+\sqrt{\frac{\gamma(\gamma^2-3\gamma+4)}{(1+\gamma)(2-\gamma)^2}}\right\},$$ *and*

$$1_{\{\alpha=1\}}=\begin{cases}1 & if\ \alpha=1\\ 0 & if\ \alpha\ne 1\end{cases}$$

1) $p_e^2(p_i^1)$ when $p_i^1=p_i^{1L}$ can be obtained by substituting $D_e=0$ and p_i^M of equation (5) into equation (2).

Proof. Propositions 5 and 6 show p_i^{1H} must satisfy the following conditions: $p_i^{1H} \le \underline{p_H}$ or $p_i^{1H} \ge \overline{p_H}$, and $\underline{p_L} \le p_i^{1H} \le \overline{p_L}$. If $\overline{p_H} \ge \overline{p_L}$, we get the inequalities in (a). Let $f(\alpha) = 1 - \frac{(1-\gamma)(2-\gamma+\gamma\alpha)^2}{(1+\gamma)(2-\gamma)^2}$ when $\alpha \ge 1$. Then $f(\alpha)$ decreases in α because γ is between 0 and 1 and $f(1) = \frac{\gamma(\gamma^2-3\gamma+4)}{(1+\gamma)(2-\gamma)^2}$. Finally, we get $\overline{p_H} = \frac{\alpha A_L}{2(1-\gamma)}\{1+\sqrt{f(1)}\} \ge \frac{A_L}{2(1-\gamma)}\{1+\sqrt{f(\alpha)}\} \ge \overline{p_L}$. Therefore, $\overline{p_H} \ge \overline{p_L}$. Also, since $\overline{p_H} = \overline{p_L}$ when $\alpha = 1$, (b) is satisfied. The rest of the conditions from (c) to (g) follow from Lemmas 3 and 4, and equation (10). □

It is possible to have two separate ranges of p_i^{1H} in this model. The following corollary gives such an example, where two demand states have equal market size. These two distinct values of the pre-entry price set by a high-type incumbent satisfy the incentive compatibility constraints of both types.

Corollary 8. *When $\alpha = 1$, p_i^{1H} has two following separate solutions in equilibrium:*

$$p_i^{1H} = \frac{A_H}{2(1-\gamma)}\left\{1 - \sqrt{\frac{\gamma(\gamma^2-3\gamma+4)}{(1+\gamma)(2-\gamma)^2}}\right\}$$
$$\text{and } p_i^{1H} = \frac{A_H}{2(1-\gamma)}\left\{1 + \sqrt{\frac{\gamma(\gamma^2-3\gamma+4)}{(1+\gamma)(2-\gamma)^2}}\right\}$$

Proof. When $\alpha = 1$, i.e., $A_H = A_L$, $\overline{p_H} = \overline{p_L}$ and $\underline{p_H} = \underline{p_L}$ in Theorem 7. Two solutions of p_i^{1H} satisfy (a) and (b) of Theorem 7. □

4. Numerical Examples

In this section we examine one numerical example of a separating equilibrium in limit pricing. Suppose that $A_H = 20$, $A_L = 10$ and $\gamma = 0.3$. From the formulas in Theorem 7, we get $\underline{P_L} = \$6.29$, $\overline{P_L} = \$8.00$, and $\underline{P_H} = \$7.08$, and the profile of strategies with the belief of an entrant is listed as follows:

$$\$6.29 \le p_i^{1H} \le \$7.08$$
$$p_i^{1L} = \$7.14$$
$$p_i^{2H} = \$11.76$$
$$p_i^{2L} = \$7.14$$
$$\mu(p_i^1) = \begin{cases} 0 \;\; if \;\; p_i^1 = \$7.14 \\ 1 \;\; if \;\; p_i^1 \ne \$7.14 \end{cases}$$
$$p_e^2(p_i^1) = \begin{cases} \$12.14 \;\; if \;\; p_i^1 = \$7.14 \\ \$11.76 \;\; if \;\; p_i^1 \ne \$7.14 \end{cases}$$

In equilibrium, the incumbent experiencing a high demand state sets a price between $6.29 and $7.08, and that experiencing a low demand state chooses a pre-entry price of $7.14. Based on the belief of the entrant, any pre-entry price deviating from $7.14 makes the entrant believe the demand state is high; thus her entry takes place in the second period. It is important to observe that an incumbent with a high demand state sends a "credible" signal to the entrant by setting his price low to deter entry. In this case, the pre-entry price charged by the incumbent, p_i^{1H} ($\$6.29 \le p_i^{1H} \le \$7.08$) is much lower than $14.29, i.e., the price which maximizes the monopoly profit in period 1 from equation (5). This example shows that the incumbent can indeed use limit pricing to deter entry in a separating equilibrium under a price-based competition when the demand state is asymmetric information.

5. Conclusion

Along with a host of entry-deterrence strategies available, including excess capacity, capital invest-ments, increased advertising, and product proliferation, limit pricing is a well-known practice, whereby an incumbent firm charges a low price to deter entry of a potential entrant. In this paper, we examine the limit pricing problem under Bertrand duopoly competition when the size of the market potential is asymmetric information. In other words, the market size is fully revealed to the incumbent, while the entrant has only partial information. We explore this problem by using a signaling game wherein an incumbent with complete information moves first, and his action (pre-entry price) is fully observable by the entrant while market size is not. We analyze a separating perfect Bayesian equilibrium where each type of market potential experienced by the incumbent is revealed perfectly through his actions observed by the entrant. Our findings indicate that the incumbent lowers the pre-entry price to signal market information that affects the entrant's expectation of post-entry profits, and the incumbent's strategic behavior can lead to successful entry deterrence.

Our paper has a few limitations, most of which may naturally lead to directions for our future research. First, our model assumes that the firms produce homogeneous products and have an equivalent production cost. Although an incumbent's product is typically of better quality than an entrant's or can be manufactured at a lower cost, making this assumption enables us to focus on the role of limit pricing under conditions of information asymmetry on the size of market potential by making every other condition of the firm identical. However, if these constraints are relaxed and information regarding both quality and cost of each firm's products is common knowledge, we speculate that limit pricing would still be a viable entry-deterrence strategy for the incumbent, and that his pre-entry price would be higher than the result we obtained in this paper. Second, the time value of money is not considered in this model. This would have provided more complete results, but we believe the current model already captures enough insight into the problem without it. Finally, this paper considers only a separating perfect Bayesian equilibrium. The examination of a pooling perfect Bayesian equilibrium, where the entrant cannot distinguish the type of the demand state the incumbent faces from his action, can be reserved for the future.

References

[1] Bain, J., "A note on pricing in monopoly and oligopoly," *American Economic Review*, Vol.39 (1949), pp.448-464.

[2] Balasubramanian, S. and P. Bhardwaj, "When not all conflict is bad: manufacturing-marketing conflict and strategic incentive design," *Management Science*, Vol.50 No.4(2004), pp.489-502.

[3] Besanko, D., D. Dranove, M. Shanley, and S. Schaefer, *Economics of Strategy*, New York : Wiley, 2009.

[4] Dixit, A., "A model of duopoly suggesting a theory of entry barriers," *The Bell Journal of Economics*, Vol.10, No.1(1979), pp.20-32.

[5] Dixit, A., "The role of investment in entry-deterrence," *The Economic Journal*, Vol.90, No.357(1980), pp.95-106.

[6] Fudenberg, D. and J. Tirole, *Game Theory*, The MIT Proess, Cambridge, MA, 1991.

[7] Goolsbee, A. and C. Syverson, "How do incumbents respond to the threat of entry? Evidence from the major airlines," *Quarterly Journal of Economics*, Vol.123, No.4(2008), pp.1611-1633.

[8] Hong, S., "Evaluation of TQM Implementation in manufacturing-based R&D organizations,"

Journal of the Korean Operations Research and Management Science Society, Vol. 34, No.1(2009), pp.101-121.

[9] Jang, D., Y. Jung, and B. Ahn, "Two-sided market and entry," *Journal of the Korean Operations Research and Management Science Society*, Vol.31, No.4(2006), pp.105-123.

[10] Karaer, O. and F. Erhun, "Quality and entry deterrence," *European Journal of Operational Research*, Vol.240(2015), pp.292-303.

[11] Lee, H., "Effect of product variety on market share," *Journal of the Korean Operations Research and Management Science Society*, Vol.29, No.1(2004), pp.101-112.

[12] Milgrom, P. and J. Roberts, "Limit pricing and entry under incomplete information : An equilibrium analysis," *Econometrica*, Vol.50, No.2 (1982), pp.443-459.

[13] Schmalensee, R., "Entry deterrence in the ready-to-eat breakfast cereal industry," *The Bell Journal of Economics*, Vol.9, No.2(1978), pp.305-328.

[14] Schmalensee, R., "Advertising and entry : An exploratory model," *The Journal of Political Economy*, Vol.91, No.4(1978), pp.636-653.

[15] Seamans, R., "Threat of entry, asymetric information and pricing," *NET Institute Working Paper* No. 08-13, 2011.

[16] Smiley, R., "Empirical evidence on strategic entry deterrence," *International Journal of Industrial Organization*, Vol.6(1998), pp.167-180.

[17] Spence, M., "Entry, capacity, investment, and oligopolistic pricing," *The Bell Journal of Economics*, Vol.8, No.2(1977), pp.534-544.

[18] Spence, M., "Investment strategy and growth in a new market," *The Bell Journal of Economics*, Vol.10, No.1(1979), pp.1-19.

[19] Tadelis, S., *Game Theory : An Introduction*, Princeton University Press, Princeton and Oxford, 2013.