Vertically Differentiated Information Goods: Monopoly Power Through Versioning

Xueqi (David) Wei[†]

and

Barrie R. Nault[††]

[†]School of Management
Fudan University
weixueqi@fudan.edu.cn

[††]Haskayne School of Business
University of Calgary
nault@ucalgary.ca

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Abstract

We analyze price, quality and versioning strategies that information goods producers use to deter entry and maintain monopoly market power. We find that under competition, firms provide higher quality information goods with a better "price-quality ratio" than in monopoly. In a Stackelberg game, a leader that provides the high quality information good decreases its quality level to maintain a first mover advantage. We also show that a monopolist can implement versioning strategies in the low-end market to deter entry, and different versions exist as a signal to prevent potential entry. A vertically differentiated market is often referred to as "natural oligopoly" for traditional goods, whereas it can be regarded as "natural monopoly" for information goods.

Keywords: Information Goods, Versioning Strategies, Pricing Strategies, Duopoly Competition, Entry Deterrence.

1 Introduction

Information goods come in many forms. Jones and Mendelson (2008) categorize information goods as computer software including operation systems, programming tools and applications; online services such as internet search engines and portals; online content such as information provided by Lexis/Nexis, Dow Jones, and Reuters; and other information goods such as digitalized music, movies and books. In each form an additional unit can be produced and distributed at negligible cost either by copying or by allowing it to be downloadable over the Internet. For the latter, broad adoption of e-commerce, secure and convenient online payments and high-speed internet connections greatly lower the transaction costs. Therefore, information goods are characterized by large sunk costs of development and by negligible costs of reproduction and distribution (Shapiro and Varian, 1999).

Another characteristic of information goods is that after the highest quality version has been developed, the costs of creating vertically degraded versions - versions with less functionality - are usually negligible. Versioning in this setting is to offer a vertically differentiated product line to segment the market and maximize profit, which is often referred to as second degree price discrimination (Wei and Nault, 2009). Hahn (2001) states that "*the functional quality degradation (of software) is an effective consumer screening device, especially when consumers' valuation for each function is negatively correlated (p.1)*". Bhargava and Choudhary (2008) reach a similar conclusion under relatively general settings about consumer heterogeneity and utility functions.

With the ease of versioning, product differentiation and pricing strategies for information goods are different from traditional goods, especially in the context of competition. Leaders with information goods usually have substantial market power. As of 2009, Microsoft Windows controlled 92.52% of the global desktop operation systems market (Net Applications. Retrieved December 28, 2009). Oracle's market share on Linux was 75.8% in 2008 (www.oracle.com), and according to Experian Hitwise the most popular search engine on the web, Google, had a U.S. market share of 71.6% in November 2009, ahead of Yahoo! (15.4%) and Bing (9.3%) (http://www.hitwise.com, December 2009). Competition in information goods is more intense than traditional goods in the sense that direct competition can drive prices to zero and both firms lose their development costs, but is less intense in the sense that the winners (often the first movers) usually dominate the market. Meanwhile, with potential competition, producers of information goods have strong incentives to improve quality, launching their highest quality version, or upgrading older versions, whenever possible. This is true even if they lose money at the margin by cannibalizing the existing market share of the old version (Nault and Vandenbosch, 1996; 2000). It is also common for the software producers to release a buggier product early and patch it later to capture the "first mover advantage" (Arora, Caulkins, and Telang, 2006). In the context of these stylized facts we examine two research questions. The first is to explain in more detail why leaders in information goods dominate their markets. The second is to explain why potential competition motivates a monopolist to increase quality and to version.

Competition with information goods has been investigated in previous research. Nault (1997) examined quality differentiation using inter-organizational information systems (IOS) and found that IOS could separate consumers and reduce competition in duopoly. Dewan, Jing and Seidmann (2003) developed a duopoly model where firms could produce both standard and customized products, finding that "*when firms face a fixed entry cost and adopt customization sequentially, the first follower always achieves an advantage and may be able to deter subsequent entry by choosing its customization scope strategically (p. 1055)*". Choudhary, Ghose, Mukopadhyay and Rajan (2005) proposed a personalized pricing (PP) strategy where firms produce vertically differentiated goods and can perfectly identify valuations of heterogeneous consumers. They found that "*while PP results in a wider market coverage, it also leads to aggravated price competition between firms (p. 1120)*". Lee and Mendelson (2007) investigated adoption of information technology (IT) by competing firms with network effects, showing that "*the balance of network effects and customer preferences sometimes creates a winner-take-all situation (p. 408)*". Empirical research has also examined product and pricing strategies. Nault and Dexter (1995) found that the adoption of cardlock IT in commercial fueling successfully differentiated a commodity (fuel), maintaining a price premium between $5-12\%$ of retail. Cottrell and Nault (2004) found that in the microcomputer software industry changes in product variety through new product introductions improve firm performance, but extensions to existing products hinder the performance of the firm and the product. Analyzing Amazon.com, Ghose, Smith and Telang (2006) found that used books are poor substitutes for new books for most customers, but the existence of used book marketplace increases consumer surplus and total welfare. Also using data from Amazon.com, Ghose and Sundararajan (2005) found that an increase in the total number of versions is associated with an increase in the difference in quality between the highest and lowest quality versions.

We use a duopoly model to analyze the price and quality choices for information goods, and examine the effectiveness of versioning strategies as a way for a monopolist to deter entry. We find that under competition firms always provide higher quality information goods with a better “price-quality ratio” than in monopoly. In addition, as long as the implementation of versions in the market is irrevocable, then in the high-end market (market for the highest quality information goods) a monopolist can set its quality to deter entry, and in the low-end market (market for all lower quality information goods) the monopolist can implement versioning to deter entry. Whereas a vertically differentiated market is often referred to as a “natural oligopoly” for traditional goods (Shaked and Sutton, 1983), because of versioning it can be regarded as a “natural monopoly” for information goods.

Our paper proceeds as follows. We set up our notation and assumptions in Section 2, briefly analyze the monopoly producer in Section 3, and examine a simultaneous move duopoly in Section 4. In Section 5, we examine a sequential move duopoly with entry deterrence. Social welfare implications are analyzed in Section 6. Discussion and future research are included in Section 7.

2 Notation and Assumptions

In our model, consumers are heterogeneous and uniformly distributed in their individual taste for quality. We denote individual consumer taste as θ which is normalized to be in the interval $[0, 1]$. The consumer taste θ indicates a consumer’s marginal valuation for quality. A consumer has positive utility for one unit only. The total market size is normalized to unity. Consumers select their favorite good with quality $q \in [0, \bar{q}]$ to maximize their consumer surplus $U(q,\theta) - p$, where p is the price of the good and $\bar{q}$ is the highest quality version possible. We take a consumer's utility to be multiplicative in taste and quality. This is our first assumption:

Assumption 1 $U(q,\theta) = \theta\, q.$

If a firm produces an information good of quality q, then it incurs development cost $C(q)$ and zero marginal cost of reproduction and distribution. The development cost $C(q)$ is twice differentiable, strictly increasing and strictly convex in q for $q > 0$, and zero quality is costless:

Assumption 2 *For $q > 0$, $C'(q) > 0$ and $C''(q) > 0$. $C(0) = 0$*

Denoting different quality versions with superscripts, after the highest quality, q^h, of the information good is produced when balancing revenue and cost, $q^h < \bar{q}$. The firm may degrade it to generate a lower quality version q^l. Taking the example of software, after the highest quality good is developed, lower quality versions can be generated either by removing, disabling or recombining functions. It is well recognized that additional costs to create the low-quality versions are small compared to development costs (Bhargava and Choudhary 2008), we assume zero versioning costs after the highest quality information goods have been developed.

Assumption 3 *Versioning costs are zero after the highest quality information goods have been produced.*

Firms know the distribution of consumers but not their individual type. Thus, only second degree price discrimination is possible. Firms choose price, quality and versioning strategies to maximize profits. This and notation used later are summarized in Table 1 in the Appendix.

Pricing of information goods must satisfy two general constraints: the individual rationality (IR) condition and the incentive compatibility (IC) condition.

IR: For each consumer θ who purchases an information good with quality q, $U(q,\theta)-p \geq 0$.

IC: For each consumer θ who purchases an information good with quality q, $U(q,\theta) - p \geq U(q_i,\theta) - p_i$, where p_i and q_i are price and quality of any alternative good.

The IR condition ensures that a consumer always gets non-negative surplus from the transaction and the IC condition ensures a consumer prefers the good that maximizes their net surplus. Demand for version i with price p_i and quality q_i is denoted as $D(p_i, q_i)$. The profit of a firm that offers N versions of the information good is

$$\Pi(p_1, \cdots, p_N, q_1, \cdots, q_N) = \sum_{i=1}^{N} p_i D(p_i, q_i) \quad \ni \quad [\mathrm{IR}], \quad [\mathrm{IC}]. \tag{1}$$

3 A Monopoly Model

In our formulation, as already shown in Jones and Mendelson (2008), Bhargava and Choudhary (2001) and basic arguments of Jing (2002) and Wu, Chen and Anandalingam (2003), a monopolist provides only one version. We denote the optimal profits of the monopolist by Π_M and the optimal price and quality of the only version by p_M and q_M, respectively. The optimal "price-quality ratio" is denoted by $r_M = p_M/q_M$. Thus the monopolist's optimal profit function can be written as

$$\Pi_M(q_M) = p_M(1 - p_M/q_M) - C(q_M).$$

For a monopolist, we have the following proposition:[1]

Proposition 1 (Monopoly) *The necessary condition for a monopolist to profitably launch the good is that the marginal cost of development is greater than the average cost of quality.*

With our assumptions the optimal "price-quality ratio" of the good provided by the monopolist is 1/2 and at the optimal price-quality ratio only half of the market is covered. As quality is also chosen, if development costs are sufficiently large, then the monopolist may find it unprofitable to launch the good even at the optimal quality level.

4 Simultaneous Move Duopoly

In this section we examine the case where two firms A and B are in the market, and each develops their version quality. We take the information goods as vertically differentiated. We formulate our basic model where neither firm considers versioning. Later we show that it is profit maximizing for each firm to provide only one version even when versioning is possible. After the information goods are produced, both firms choose prices. Consumers choose their preferred goods based on the qualities and prices. Thus, our model is a two-stage game where in Stage 1 firms A and B develop information goods with quality levels q_A and q_B, and in Stage 2 the firms compete in prices.

[1]Proofs are included in the Appendix.

4.1 Simultaneous Move without Versioning

We consider a pure strategy Nash equilibrium of the game. If both firms develop information goods with the same quality level, Bertrand competition drives prices to zero and neither firm gains positive profit.[2] Without loss of generality, we assume $q_A > q_B$. The cost for firm A to develop q_A is $C_A(q_A)$, and for firm B to develop q_B is $C_B(q_B)$. The cost functions of firms A and B need not be the same. For both firms to have positive share, $p_A > p_B$.

Let θ_A denote the consumer indifferent between buying goods q_A and q_B, and θ_B denote the consumer indifferent between buying good q_B and not buying. Similar to the analysis in the previous section, we have $\theta_A = [p_A - p_B]/[q_A - q_B]$, and $\theta_B = p_B/q_B$. We work backwards to solve the duopoly model.

Stage 2 Firm A and B's profit functions are

$$\Pi_A(p_A, p_B) = p_A \left[1 - \frac{p_A - p_B}{q_A - q_B}\right] - C_A(q_A) \text{ and } \Pi_B(p_A, p_B) = p_B \left[\frac{p_A - p_B}{q_A - q_B} - \frac{p_B}{q_B}\right] - C_B(q_B).$$

The first-order conditions with respect to own prices yield best response functions [3]

$$2p_A - p_B = q_A - q_B \text{ and } p_A/[2p_B] = q_A/q_B. \tag{2}$$

Solving for the equations in (2) gives

$$p_A = 2q_A \left[\frac{q_A - q_B}{4q_A - q_B}\right] \text{ and } p_B = q_B \left[\frac{q_A - q_B}{4q_A - q_B}\right]. \tag{3}$$

From (3) the market share for q_A is $2q_A/[4q_A - q_B]$, which is twice the market share of q_B.

[2]Both firms providing goods with the same quality is not a Nash equilibrium. If H is the high quality good and L is the low quality good, the possible combinations of goods provided by the two firms are (H, H), (H, L), (L, H) and (L, L). Only (H, L) and (L, H) are Nash equilibria.

[3]The sufficient second order conditions are satisfied for this and the remaining optimization problems. Details are available upon request.

Stage 1 Substituting (3) back into the profit functions of firms A and B, we have

$$\Pi_A(q_A, q_B) = 4q_A^2 \left[q_A - q_B\right] / \left[4q_A - q_B\right]^2 - C_A(q_A) \tag{4}$$

and

$$\Pi_B(q_A, q_B) = q_A q_B \left[q_A - q_B\right] / \left[4q_A - q_B\right]^2 - C_B(q_B). \tag{5}$$

$\Pi_A(q_A, q_B)$ is concave in q_A and $\Pi_B(q_A, q_B)$ is concave in q_B (Proofs are in the Appendix). Firms A and B choose quality levels q_A and q_B to maximize their profits, thus $\partial\Pi_A(\cdot)/\partial q_A = 0$ and $\partial\Pi_B(\cdot)/\partial q_B = 0$. The equilibrium quality levels q_A and q_B are implicitly determined by

$$C'_A(q_A) = 4q_A \left[4q_A^2 - 3q_A q_B + 2q_B^2\right] / \left[4q_A - q_B\right]^3 \tag{6}$$

and

$$C'_B(q_B) = q_A^2 \left[4q_A - 7q_B\right] / \left[4q_A - q_B\right]^3. \tag{7}$$

4.2 Should Firms Version?

In the following, we show that even when versioning is an option for both firms, neither version their information goods. In terms of which firm considers versioning, there are two situations.

Firm A considers versioning. Here we assume firm A develops its high quality version q_A^H and generates a lower version q_A^L, and firm B develops its quality q_B. Prices p_B, p_A^H and p_A^L are set according to Bertrand competition. There are two cases:

Case 1: $q_A^L < q_B < q_A^H$. Let θ_A^H denote the consumer indifferent between buying q_A^H and q_B, θ_B denote the consumer indifferent between buying q_B and q_A^L, and θ_A^L denote the consumer indifferent between buying q_A^L and not buying. We have $\theta_A^H = \left[p_A^H - p_B\right] / \left[q_A^H - q_B\right]$, $\theta_B = \left[p_B - p_A^L\right] / \left[q_B - q_A^L\right]$, and $\theta_A^L = p_A^L / q_A^L$. The profit function of firm A is

$$\Pi_A(p_A^H, p_A^L, p_B) = p_A^H \left[1 - \frac{p_A^H - p_B}{q_A^H - q_B}\right] + p_A^L \left[\frac{p_B - p_A^L}{q_B - q_A^L} - \frac{p_A^L}{q_A^L}\right] - C_A(q_A^H) - V. \tag{8}$$

The profit function for firm B is

$$\Pi_B(p_A^H, p_A^L, p_B) = p_B \left[\frac{p_A^H - p_B}{q_A^H - q_B} - \frac{p_B - p_A^L}{q_B - q_A^L}\right] - C_B(q_B). \tag{9}$$

Substituting the equilibrium prices as functions of quality[4] back into the profit function of firm A, we have

$$\Pi_A(q_A^H, q_A^L, q_B) = \frac{\left[q_A^H - q_B\right]}{\left[\Lambda_1\right]^2} \left[\left[4q_A^H q_B - q_A^H q_A^L - 3q_B q_A^L\right]^2 + q_B q_A^L \left[q_A^H - q_B\right]\left[q_B - q_A^L\right]\right] - C_A(q_A^H) - V,$$

where $\Lambda_1 = 2\left[4q_A^H q_B - q_A^H q_A^L - q_B^2 - 2q_B q_A^L\right]$. Taking the partial derivative of $\Pi_A(\cdot)$ with respect to q_A^L,

$$\frac{\partial \Pi_A(q_A^H, q_A^L, q_B)}{\partial q_A^L} = \frac{-2q_B^2 \left[q_A^H - q_B\right]^2}{\left[\Lambda_1\right]^3} \left[20q_A^H q_B + q_A^H q_A^L + q_B^2 - 22q_B q_A^L\right] < 0.$$

The negative sign comes from $q_A^L < q_B < q_A^H$, which means that increasing the quality of its lower version reduces firm A's profit. Consequently, it is not optimal for firm A to version its information good.

Case 2: $q_B < q_A^L < q_A^H$**.** Let θ_A^H denote the consumer indifferent between buying q_A^H and q_A^L, θ_A^L denote the consumer indifferent between buying q_A^L and q_B, and θ_B denote the consumer indifferent between buying q_B and not buying. We have $\theta_A^H = \left[p_A^H - p_A^L\right] / \left[q_A^H - q_A^L\right]$, $\theta_A^L = \left[p_A^L - p_B\right] / \left[q_A^L - q_B\right]$, and $\theta_B = p_B / q_B$. Firm A's profit function is

$$\Pi_A(p_A^H, p_A^L, p_B) = p_A^H \left[1 - \frac{p_A^H - p_A^L}{q_A^H - q_A^L}\right] + p_A^L \left[\frac{p_A^H - p_A^L}{q_A^H - q_A^L} - \frac{p_A^L - p_B}{q_A^L - q_B}\right] - C_A(q_A^H) - V, \tag{10}$$

[4] Details are shown in equations (15), (16) and (17) in the Appendix.

and firm B's profit function is

$$\Pi_B(p_A^H, p_A^L, p_B) = p_B \left[\frac{p_A^L - p_B}{q_A^L - q_B} - \frac{p_B}{q_B} \right] - C_B(q_B). \tag{11}$$

Substituting the equilibrium prices as functions of quality[5] back into the profit function of firm A, we have

$$\Pi_A(q_A^H, q_A^L, q_B) = \frac{16 q_A^H q_A^L \left[q_A^L - q_B \right] + q_B \left[q_A^H - q_A^L \right] \left[8 q_A^L + q_B \right]}{\left[\Lambda_2\right]^2} - C_A(q_A^H) - V,$$

where $\Lambda_2 = 2\left[4q_A^L - q_B\right]$. Taking the partial derivative of Π_A with respect to q_A^L, we have,

$$\frac{\partial \Pi_A(q_A^H, q_A^L, q_B)}{\partial q_A^L} = \frac{2\left[q_B\right]^2 \left[20 q_A^L + q_B\right]^2}{\left[\Lambda_2\right]^3} > 0.$$

The positive sign comes from $q_B < q_A^L < q_A^H$, which means that increasing the quality of its lower version monotonically increases firm A's profit, and firm A sets $q_A^L = q_A^H$. So it is still not optimal for firm A to version its information good.

Firm B considers versioning. Here we assume firms A and B develop their highest quality version q_A and q_B^H, respectively. Firm B degrades q_B^H to generate a lower quality version q_B^L. We have $q_B^L < q_B^H < q_A$. Prices p_A, p_B^H and p_B^L are set according to Bertrand competition.

Let θ_A denote the consumer indifferent between buying q_A and q_B^H, θ_B^H denote the consumer indifferent between buying q_B^H and q_B^L, and θ_B^L denote the consumer indifferent between buying q_B^L and not buying. We have $\theta_A = \left[p_A - p_B^H\right] / \left[q_A - q_B^H\right]$, $\theta_B^H = \left[p_B^H - p_B^L\right] / \left[q_B^H - q_B^L\right]$, and $\theta_B^L = p_B^L / q_B^L$. The profit function of firm A is

$$\Pi_A(p_A, p_B^H, p_B^L) = p_A \left[1 - \frac{p_A - p_B^H}{q_A - q_B^H} \right] - C_A(q_A),$$

[5]Details are shown in equations (18), (19) and (20) in the Appendix.

and the profit function of firm B is

$$\Pi_B(p_A, p_B^H, p_B^L) = p_B^H \left[\frac{p_A - p_B^H}{q_A - q_B^H} - \frac{p_B^H - p_B^L}{q_B^H - q_B^L}\right] + p_B^L \left[\frac{p_B^H - p_B^L}{q_B^H - q_B^L} - \frac{p_B^L}{q_B^L}\right] - C_B(q_B^H) - V. \quad (12)$$

From the first order conditions of (12) with respect to p_B^L, we get

$$\frac{p_B^H - p_B^L}{q_B^H - q_B^L} = \frac{p_B^L}{q_B^L},$$

which means that $\theta_B^H = \theta_B^L$ and there is no market for q_B^L. So it is not optimal for firm B to version its information good.

The above analysis can be extended to the cases when both firms consider versioning (details are in the Appendix). Thus, in a simultaneous move duopoly, we have the following proposition:

Proposition 2 (Simultaneous Game) *In a simultaneous move duopoly game, each firm provides only one version.*

4.3 Comparative Quality Analysis

We denote the equilibrium price-quality ratio of the goods provided by each firm by $r_j = p_j/q_j \;\; j \in \{A, B\}$. We also denote the "comparative quality ratio" by t where $t = q_A/q_B > 1$ from $q_A > q_B$. Thus, the solutions for p_A and p_B in (3) can be rewritten as

$$r_A = 2\,[t-1]\,/\,[4t-1] \;\text{ and }\; r_B = [t-1]\,/\,[4t-1]\,.$$

Under our assumptions the optimal price-quality ratio of the good provided by firm A is twice as much as that provided by firm B. For $t > 1$, we have $r_A < 1/2$ and $r_B < 1/4$. Using Proposition 1, both firms provide goods with better price-quality ratios than the monopolist.

From (3) we get $\theta_A = [2t-1]/[4t-1] < 1/2$, thus $1-\theta_A = 2t/[4t-1] > 1/2$. This indicates that firm A has a market share of more than 1/2, which is larger than that of the monopolist. Also we have $\theta_B = [t-1]/[4t-1] < 1/4$, thus $\theta_A - \theta_B = t/[4t-1] > 1/4$. This indicates that the total market served is more than 3/4. We know in monopoly only half of the market is served, therefore the total market served expands more than 50 percent in duopoly.

From (6) and (7), we have $C'_A(q_A) > 1/4$ and $C'_B(q_B) < 1/16$ for $q_A > q_B$. If firms have the same development cost, $C_A(q) = C_B(q)$, then $q_B < q_M < q_A$. This means that the high and low quality firms produce information goods with qualities that bracket the quality chosen by a monopolist. So we have the following proposition:

Proposition 3 (Simultaneous vs. Monopoly) *i) With equal development cost, the high quality firm produces a higher quality good than a monopolist. ii) Both firms provide goods with better price-quality ratios than in monopoly.*

4.4 Best Response Functions and Equilibrium Analysis

In the following we discuss some characteristics of the best response functions of firm A and B. For $q_A > q_B$, we denote the best response functions of firm A and B by $q_A = q_A^*(q_B)$ and $q_B = q_B^*(q_A)$, respectively. And for $q_A < q_B$, we denote the best response functions of firm A and B by $q_A = q_A^{\prime *}(q_B)$ and $q_B = q_B^{\prime *}(q_A)$, respectively.

The best response function $q_A = q_A^*(q_B)$ is implicitly defined by (6). Rewriting (6) to emphasize this, we have $C'_A(q_A^*) \equiv 4q_A^* \left[4\left[q_A^*\right]^2 - 3q_A^* q_B + 2q_B^2\right] / \left[4q_A^* - q_B\right]^3$. Taking the first derivative with respect to q_B, we have

$$\frac{dq_A^*(\cdot)}{dq_B} = \frac{8q_A q_B \left[5q_A + q_B\right]}{C_A''(q_A)\left[4q_A - q_B\right]^4 + 8q_B^2\left[5q_A + q_B\right]} > 0.$$

This means that the best response quality q_A increases in q_B. Similarly, the best response function $q_B = q_B^*(q_A)$ is implicitly defined by (7), and rewriting gives $C_B'(q_B^*) \equiv q_A^2\left[4q_A - 7q_B^*\right] / \left[4q_A - q_B^*\right]^3$. Taking the first derivative with respect to q_B, we have

$$\frac{dq_B^*(\cdot)}{dq_A} = \frac{2q_A q_B \left[8q_A + 7q_B\right]}{C_B''(q_B)\left[4q_A - q_B\right]^4 + 2q_A^2\left[8q_A + 7q_B\right]} > 0.$$

Thus, the best response quality q_B increases in q_A.

The analysis is symmetric for $q_A < q_B$, where we have the best response functions $q_A = q_A'^*(q_B)$ and $q_B = q_B'^*(q_A)$. Diagram 1 depicts the shape of the best response functions.

*** Insert Diagram 1 Here ***

If the competing firms have the same development cost, then there are two equilibria where either firm A or B can provide high quality good while the other firm provides low quality good (Jones and Mendelson, 2005). As is shown in Diagram 1, if $q_A > q_B$, then the equilibrium is N, and if $q_A < q_B$, then the equilibrium is N'. However, if the development cost functions differ for the competing firms, then it is possible that there is only one equilibrium where the firm with the development cost advantage develops the high quality good. For example, firm B with superior technology may find it more profitable to develop the information good with higher quality q_B^H instead of q_B^N, thus the equilibrium point goes to N'.

5 Sequential Move: Strategic Accommodation and Entry Deterrence

In this section we analyze the situation where one firm enters the market earlier than the other. Thus there are three stages: leader chooses quality and whether to version, the follower observes this and chooses quality and whether to enter, and then prices are set. In this sequential duopoly game, the leader can accommodate or deter entry through its choice of quality and whether to version. If the leader accommodates entry, then it is a Stackelberg game where a first mover advantage is obtained by strategically setting quality. Alternatively, the leader may find it profit maximizing to deter entry. In this case, we show that the leader can strategically set quality to deter entry from the high-end market while implementing a versioning strategy to deter entry from the low-end market. Development cost determines whether the leader accommodates or deters entry.

5.1 Entry Accommodation - A Stackelberg Solution

In the sequential move (Stackelberg) duopoly game, we denote the leader as A and the follower as B. Consider first a game of entry accommodation. The leader first develops an information good of quality q_A and sets price p_A. Then the follower determines whether to enter the market. If entry is profitable, the follower determines its best response quality q_B and then firms compete in prices. Consumers choose their preferred goods after the qualities and prices are determined.

Working backwards, the leader chooses q_A such that $q_A > q_B$ or $q_A < q_B$. For vertical differentiation, Jones and Mendelson (2008) show that with a special exponential development cost function form for both firms, the firm with the high quality good gains the greatest profits. We start with the situation where the leader prefers $q_A > q_B$ first and then discuss the situation where leader chooses $q_A < q_B$.

We write the follower's best response function as $q_B = q_B(q_A)$. The quality provided by the leader is determined by

$$\max_{q_A} \Pi_A(q_A, q_B(q_A)).$$

From the first order condition, we have

$$\frac{d\Pi_A(q_A, q_B(q_A))}{dq_A} = \frac{\partial\Pi_A(q_A, q_B(q_A))}{\partial q_A} + \frac{\partial\Pi_A(q_A, q_B(q_A))}{\partial q_B}\frac{dq_B}{dq_A} = 0. \tag{13}$$

Because $\Pi_A(q_A, q_B(q_A))$ can be written as $\Pi_A(q_A, q_B)$ in (4), we have

$$\frac{\partial\Pi_A(q_A, q_B)}{\partial q_B} = -\frac{4q_A^2\left[2q_A + q_B\right]}{\left[4q_A - q_B\right]^3} < 0. \tag{14}$$

The best response function $q_B(q_A)$ is determined implicitly by (7) and is increasing in q_A. Thus, we have $dq_B(q_A)/dq_A > 0$. From (13), we have $\partial\Pi_A(q_A, q_B(q_A))/\partial q_A > 0$ at the Stackelberg point.

We know for the simultaneous game, at the Nash equilibrium, $\partial\Pi_A(q_A, q_B)/\partial q_A = 0$. Denoting the Stackelberg quality provided by the leader as q_A^S and the Nash equilibrium quality from the simultaneous game as q_A^N, from the concavity of $\Pi_A(q_A, q_B)$ in q_A, we have $q_A^S < q_A^N$. It means with the first mover advantage, the leader lowers quality to increase profit.

This result is interesting. In a traditional Stackelberg game with quantities, the leader increases quantity to gain first mover advantage (Church and Ware, 2000, p.468-470), while in our model of quality and price competition, the leader decreases quality.

If the follower has lower development costs, then the Stackelberg game may have another outcome. As is shown in Diagram 2, the follower with lower development costs may find it more profitable to develop an information good with higher quality than q_A^S, which means $\Pi_B(q_A^S, q_B^S) < \Pi_B(q_A^S, q_B^H)$. As shown in Section 5.4 numerically, if the follower has "much lower" development costs, then the leader chooses $q_A < q_B$. For $q_A < q_B$, we find that as compared to the simultaneous game, with a first mover advantage the leader increases its quality (details are in the appendix).

*** Insert Diagram 2 Here ***

To summarize the above, we have the following proposition:

Proposition 4 (Stackelberg) *Compared to a simultaneous game, in a Stackelberg game a leader that provides a high quality good decreases quality, and a leader that provides a low quality good increases quality.*

5.2 Entry Deterrence

In the Stackelberg game above, we assumed that the leader accommodates entry. But the leader can also deter entry with its choice of quality. In the following we show that in a sequential game, the first mover can set information good quality to deter entry from the high-end market while implementing a versioning strategy to deter entry from the low-end market.

5.2.1 Entry Deterrence from the High-end Market

To begin we analyze potential entry in the high-end market, which means that the follower develops quality $q_B > q_A$. Once entry occurs, the equilibrium prices and profits of both firms are determined in the same manner as in the simultaneous game. Thus, we have the equilibrium profits as in (4) and (5) except with A and B reversed.

Taking the total derivative of $\Pi_B(q_A, q_B(q_A))$ with respect to q_A, we have

$$\frac{d\Pi_B(q_A, q_B(q_A))}{dq_A} = \frac{\partial \Pi_B(q_A, q_B(q_A))}{\partial q_A} + \frac{\partial \Pi_B(q_A, q_B(q_A))}{\partial q_B}\frac{dq_B}{dq_A}$$

The first term of the right hand side of the equation has the same form as (14), except with A and B reversed, and it is negative. For the second term, from the analysis of the best response functions in Section 4.4, the follower's quality increases when the leader increases quality, so we have $dq_B/dq_A > 0$. Because $\Pi_B(q_A, q_B)$ is concave in q_B and the entry deterrence quality q_B is never lower than the Nash equilibrium quality, we get that $\partial\Pi_B(q_A, q_B(q_A))/\partial q_B$ is non-positive. Therefore, $d\Pi_B(q_A, q_B(q_A))/dq_A$ is negative, which means when q_A increases, the follower's profit decreases. Thus, the leader can strategically set quality such that the profit of the follower from the high-end market is zero. This entry deterrence quality is jointly determined by the above profit constraint and the follower's best response function.[6]

When the leader successfully deters entry, it acts as a monopolist. We denote the entry deterrence quality of the leader by q_A^E, and the monopoly quality and profit from Section 3 by q_M and $\Pi_M(q)$, respectively. The entry deterrence quality q_A^E is not lower than q_M, otherwise the leader can safely produce at q_M and deter entry. Thus we get $q_M \leq q_A^E < q_B$.[7] From the

[6]It is the same as equation (6), only with A and B reversed.

[7]q_B is the quality of the entry when $\Pi_B(q_A, q_B) = 0$. Theoretically, entry is deterred in this case.

concavity of $\Pi_M(\cdot)$, we have $\Pi_M(q_M) \geq \Pi_M(q_A^E) > \Pi_M(q_B)$. With equal development costs, $\Pi_M(q_B) > \Pi_B(q_A, q_B) = 0$ because a monopolist always earns more profits. Thus we get the monopoly profits of the leader under entry deterrence are positive, which means the leader can always profitably deter entry.

From discussions in this section, we have the following proposition.

Proposition 5 (Entry Deterrence) *i) The leader can strategically set quality to deter entry from the high-end market. ii) With equal development costs, the leader can always profitably deter entry.*

Similar to the "top dog strategy" that overinvestment in capacity makes the leader tougher (Fudenberg and Tirole, 1984) and the threat of a predatory output increase after entry made credible by carrying excess capacity prior to entry (Dixit, 1980), with information goods the leader chooses to overinvest in development to deter entry. If the leader has sunk its development costs to produce the entry deterrence quality, then the enhanced quality is always a credible threat to the follower. Lee and Mendelson (2008) reached similar results under network effects. They showed that when a commercial firm competes with a free open source product, the commercial firm must increase its development investment to improve its product features in order to capitalize on its first mover advantage.

5.2.2 Entry Deterrence from the Low-end Market

When the leader strategically sets quality to deter entry from the high-end market, it opens another door to the follower - entry may occur in the low-end market. In this setting, the leader has already developed its high quality version q_A^H, and generates a low quality version

q_A^L to deter entry from the low-end market. The follower determines whether to enter, and if entry is profitable, then the follower determines its quality q_B, and firms compete in prices. Consumers select their preferred goods after the qualities and prices of the information goods are determined.

In this model we assume $q_A^L < q_B < q_A^H$.[8] This is the same setting as the Case 1 when firm A considers versioning in Section 4.2, only with different objective that here the leader chooses the quality of its lower quality version, q_A^L, so that the follower gets non-positive profits. Substituting the equilibrium prices into the profit function for firm B in (9), we have

$$\Pi_B(q_A^H, q_B, q_A^L) = \frac{4q_B^2 \left[q_A^H - q_B\right] \left[q_A^H - q_A^L\right] \left[q_B - q_A^L\right]}{\Lambda^2} - C_B(q_B).$$

Taking the partial derivative of $\Pi_B(\cdot)$ with respect to q_A^L, we have,

$$\frac{\partial \Pi_B(q_A^H, q_B, q_A^L)}{\partial q_A^L} = \frac{-8q_B^2 \left[q_A^H - q_B\right]^2}{\Lambda_1^3} \left[2q_A^H q_B + q_A^H q_A^L + q_B^2 - 4q_B q_A^L\right] < 0.$$

It means the higher the q_A^L, the lower the profit of the follower. Therefore, the leader can use versioning q_A^L to deter entry.

In order to effectively deter entry, q_A^L must be set so that $\Pi_B(q_B) \leq 0$. Through the envelope theorem, we have $\partial \Pi_B(q_A^H, q_B, q_A^L)/\partial q_B = 0$. Thus, firm A determines q_A^L by setting the profit of the follower to zero, which is equivalent to

$$C_B'(q_B)/q_B = \frac{4q_B \left[q_A^H - q_B\right] \left[q_A^H - q_A^L\right] \left[q_B - q_A^L\right]}{\Lambda_1^2},$$

[8] One might argue that potential entry may come from an even lower-end market, which means $q_B < q_A^L$. In that case, the leader can generate another lower version to deter entry, with the same mechanism we describe here.

and the equilibrium quality q_B is determined by

$$C'_B(q_B) = \frac{8q_B\left[q_A^H - q_A^L\right]}{\Lambda_1^3}\{q_A^H\left[q_A^H - q_B\right]\left[4q_B^2 + 2\left[q_A^L\right]^2 - 3q_Bq_A^L\right]$$

$$+q_Bq_A^L\left[q_B - q_A^L\right]\left[2q_B + q_A^H\right] - 3q_B^3\left[q_A^H - q_A^L\right]\}.$$

Clearly, the optimal entry deterrence quality of the sub-version depends on the development costs of the follower. The following proposition concludes this sub-section.

Proposition 6 (Entry Deterrence) *The leader can generate low quality versions to deter entry from the low-end market.*

We denote the comparative quality ratios of q_A^H, q_B with respect to q_A^L by $t_H = q_A^H/q_A^L$ and $t_B = q_B/q_A^L$. The optimal price-quality ratio of versions q_A^H and q_A^L provided by the leader are denoted by $r_H = p_A^H/q_A^H$ and $r_L = p_A^L/q_A^L$, respectively. The price-quality ratio of versions q_B provided by the follower is denoted by $r_B = p_B/q_B$. From the equilibrium price equations (15), (16) and (17) in the Appendix, we get

$$r_H = \frac{[t_H - t_B]\,[4t_B - 1 - 3t_B/t_H]}{2\,[4t_Ht_B - t_H - 2t_B - t_B^2]}, \quad r_L = \frac{[t_H - t_B]\,[t_B - 1]}{2\,[4t_Ht_B - t_H - 2t_B - t_B^2]},$$

and

$$r_B = \frac{[t_H - t_B]\,[t_B - 1]}{[4t_Ht_B - t_H - 2t_B - t_B^2]}.$$

From the above equations, we have $r_B = 2r_L$ and $r_H > 2r_B$. It indicates that the price-quality ratio of the high quality version is more than four times that of the low quality version.

5.3 Entry Deterrence, Rivalry Clear-out or Coexistence

We know from the previous discussion that the leader can develop higher quality to deter entry from the high-end market and generate versions to deter entry into the low-end market. The key questions are whether it is profit maximizing for the leader to deter entry, and if rivalry already exists in the market, whether it is profit maximizing for one firm to drive its competitor out. If the answer of either of the above questions is "no", then the leader may choose to coexist with its competitor.

5.3.1 Rivalry Clear-out or Coexistence

We first consider the case where firms A and B are already in the market with information goods q_A and q_B, and we suppose $q_A > q_B$. Because the development costs are sunk and there is no marginal cost, a firm will not exit if the price of its good is positive. From Section 4, we know that in equilibrium, profits for firm A and B are (4) and (5).

Firm B with a lower quality information good cannot drive firm A out of the market. For firm A to drive out firm B, it can generate a lower quality version with quality q_B and prices of q_B go to zero from Bertrand competition. The equilibrium profit for firm B is zero and profit for firm A which we denote by $\Pi_A^{Clear}(q_A, q_B)$, is

$$\Pi_A^{Clear}(q_A, q_B) = [q_A - q_B]/4 - C_A(q_A)$$

The first part of the above profit equation is the revenue generated from q_A and the second part is the development costs of q_A. It is straightforward to see that $\Pi_A^{Clear}(q_A, q_B) < \Pi_A(q_A, q_B)$. Therefore, firm A is better off coexisting with firm B because a lower quality version intensifies competition, similar to Judd (1985) and Nault (1997). Therefore, versioning is not optimal in a game when both firms are already in the market.

5.3.2 Entry Deterrence and Strategic Analysis with Versioning

From the discussion earlier, we know it is always profit maximizing for the leader to generate a lower quality version to deter entry from the low-end market. And, in the high-end market, the sunk costs of development pose a credible threat to deter entry. However, entry deterrence may not be profit maximizing.

Let q_A^D be the minimum entry deterrence quality in the high-end market, as described in Section 5.2.1. If the leader produces quality less than q_A^D, then entry occurs in the high-end market. As before, let q_M be the monopoly quality of the information good from Section 3. q_M is determined by $C_A'(q_M) = 1/4$. If $q_A^D \leq q_M$, then entry in the high-end market is deterred.

If $q_M < q_A^D$, then the leader has to increase quality, which in turn decreases profits, relative to the monopolist. Recall from Section 5.1 that the leader may choose a lower quality, allowing the follower to enter with higher quality. Denote this low Stackelberg quality as $q_A^{S'}$ when accommodating entry in the high end. Let q_A^{DI} be the highest quality so that the leader is indifferent between producing high quality to deter entry and low Stackelberg quality $q_A^{S'}$. q_A^{DI} is determined by $\Pi_M(q_A^{DI}) = \Pi_A(q_A^{S'}, q_B^{S'})$. Because $\Pi_M(q_A^{DI}) < \Pi_M(q_M)$ and concavity of $\Pi_M(\cdot)$, we have $q_A^{DI} > q_M$. If $q_A^D < q_A^{DI}$, which means $\Pi_M(q_A^D) > \Pi_M(q_A^{DI}) = \Pi_A(q_A^{S'}, q_B^{S'})$, then entry deterrence is profit maximizing. Otherwise, it is profit maximizing for the leader to accommodate entry with $q_A^{S'}$.

Thus, the optimal strategies for the leader are as follows (details are in the appendix):

- If $q_A^D \leq q_M$, then the optimal quality of the information good provided by the leader is q_M. Versioning is implemented in the low-end market and entry is deterred.

- If $q_M < q_A^D < q_A^{DI}$, then the optimal quality of the information good provided by the leader is q_A^D. Versioning is implemented in the low-end market and entry is deterred.

- If $q_M < q_A^{DI} \leq q_A^D$, then the quality of the information good provided by the leader is $q_A^{S'}$. No versioning is implemented and entry is accommodated. The follower quality is $q_B^{S'}$.

5.4 A Numerical Example

Here we use a numerical example to illustrate which strategies firms adopt in different situations. Similar to Jones and Mendelson (2008), we assume development costs are quadratic in quality, $C(q) = Kq^2$. Firms differ in the parameter K: the higher the K, the higher are development costs. The indifferent quality q_A^{BI} is defined as the quality of the good produced by firm A where firm B is indifferent between producing high and low quality. The indifferent quality q_B^{AI} is defined as the quality of the good produced by firm B where firm A is indifferent between producing high and low quality.

Simultaneous Game. In Table 2, we show that if $K_A/K_B \leq 0.63$, then there is only one Nash equilibrium where firm A produces the high quality good while firm B produces the low quality good. For $0.63 < K_A/K_B < 1.59$, there are two Nash equilibria where either firm may produce the high quality good while the other firm produces the low quality good. When $K_A/K_B \geq 1.59$, then there is only one Nash equilibrium where firm B produces the high quality good while firm A produces the low quality good.

Table 2: **A Numerical Example: Simultaneous Game**

	K_A/K_B	1/3	0.63	1	1.59	2	3
$q_A > q_B$	q_A	125.2421	125.7666	126.6554	128.2485	129.326	131.648
	q_B	9.5605	16.6932	24.1193	33.2245	38.0931	46.8165
	Π_A	14.3711	13.355	12.2193	10.7125	9.8532	8.2175
	Π_B	0.2994	0.5257	0.7637	1.0648	1.2316	1.5408
$q_A < q_B$	q_A	15.6055	20.9314	24.1193	26.5422	27.4641	28.6814
	q_B	43.8827	80.7953	126.6554	199.9688	251.0219	375.7263
	Π_A	0.5136	0.6701	0.7637	0.8347	0.8616	0.8982
	Π_B	2.7392	6.7489	12.2193	21.2345	27.571	43.1132
Indifferent quality level	q_A^{BI}	26.8955	50.8325	80.6866	128.2917	161.3732	242.0597
	q_B^{AI}	80.6866	80.6866	80.6866	80.6866	80.6866	80.6866

* The development cost function is $C(q) = Kq^2$ and $K_A = 0.001$.

Stackelberg Game without Versioning. Even without versioning, in a sequential move duopoly, the leader can take the first mover advantage to reap more profit than in the simultaneous game. We show in Table 3 that if $K_A/K_B < 1.482$, then the leader can choose to produce at the Stackelberg point S as indicated in Diagram 2 where the leader produces a higher quality good than the follower. When $K_A/K_B \geq 1.482$, the leader cannot produce at Stackelberg point S because the follower is better off producing higher quality than the leader at S. When $1.482 \leq K_A/K_B < 2.572$, the leader can still get more profit by producing a higher quality good than the follower. To maximize profits, the leader produces at the point where the follower is indifferent between producing a higher quality good or a lower quality good.[9] When $K_A/K_B = 2.572$, the leader becomes indifferent between producing at the follower's indifferent point or producing at its low Stackelberg point S'. In that case, the leader should produce at its low Stackelberg point S'. Thus we get when $K_A/K_B \geq 2.572$, the leader produces a lower quality good than the follower.

[9]Strictly speaking, the leader should produce at a quality that is strictly higher than this level to prevent the follower from producing a higher quality good.

Table 3: A Numerical Example: Stackelberg Game

	K_A/K_B	1/2	1	1.482	2	2.572	3
$q_A > q_B$	q_A	124.4645	122.59	119.7105	115.9129	111.5372	108.41
	q_B	13.7145	23.913	30.973	36.1843	39.8635	41.6273
	Π_A	13.7869	12.2352	11.0283	10.0136	9.1666	8.677
	Π_B	0.4304	0.7577	0.993	1.1754	1.3128	1.3835
$q_A < q_B$	q_A	19.3227	24.197	26.2612	27.4738	28.2799	28.6908
	q_B	64.7292	126.6667	186.5366	251.0226	322.3302	375.7268
	Π_A	0.6159	0.7637	0.8254	0.8616	0.8858	0.8982
	Π_B	4.8767	12.2069	19.5666	27.5696	36.4514	43.1119
Indifferent quality level	q_A^{BI}	40.3433	80.6866	119.5775	161.3732	207.5259	242.0597
	q_B^{AI}	80.6866	80.6866	80.6866	80.6866	80.6866	80.6866

* The development cost function is $C(q) = Kq^2$ and $K_A = 0.001$.
** For the Stackelberg game, we assume firm A moves before firm B.

Entry Deterrence with Versioning. As discussed in the previous section, if versioning can deter entry from the low-end market, then the leader can set quality to deter entry from the high-end market and capture monopoly profits. For this specific development costs function, we show that if $K_A/K_B \leq 1.5$, then the leader is "natural monopoly". The leader can safely set the quality of its flagship version the same as when there is no competition and adopts versioning strategies to deter entry from below.

If the follower has much lower development costs, in our case $1.5 < K_A/K_B < 2.9563$, then the leader has to increase its quality above the monopoly quality in order to deter entry. If the follower has a substantial development costs advantage, in our case $K_A/K_B \geq 2.9563$, then entry deterrence is no longer optimal. The leader is better off choosing quality at the lower Stackelberg point S' where $q_A < q_B$, as indicated in Diagram 2. Through our analysis for the leader with and without versioning, we see that when the leader versions it acts more aggressively, that is, it tends to produce a higher quality good despite a development cost disadvantage.

Table 4: A Numerical Example: Entry Deterrence

	K_A/K_B	1/2	1	3/2	2	2.9563	3
Stackelberg Game ($q_A < q_B$)	q_A	19.3227	24.197	26.3157	27.4738	28.6542	28.6908
	q_B	64.7292	126.6667	188.7753	251.0226	370.2737	375.7268
	Π_A	0.6159	0.7637	0.827	0.8616	0.8972	0.8982
	Π_B	4.8767	12.2069	19.8436	27.5696	42.4315	43.1119
Entry Deterrence	q_A	41.6667	83.3333	125	166.6667	246.3582	250
	Π_A	8.6806	13.8889	15.625	13.8889	0.8972	0
Pure Monopoly	q_A	125	125	125	125	125	125
	Π_A	15.625	15.625	15.625	15.625	15.625	15.625

* The development cost function is $C(q) = Kq^2$ and $K_A = 0.001$.

6 Welfare Implications

Because the marginal cost of producing information goods is zero, to be socially optimal the price of the information good must also be zero. We denote the socially optimal quality by q^O and the optimal social welfare by W^O, where q^O maximizes social welfare W^O. We know $W^O(q^O) = \int_0^1 q^O\theta d_\theta - C(q^O)$, so the optimal quality is determined by $C^{'}(q^O) = 1/2$. All consumers enjoy q^O at price zero with total surplus $q^O/2$, firm incurs negative profit $-C(q^O)$ (the sunk development costs). The optimal social welfare is $W^O(q^O) = q^O/2 - C(q^O)$.

From Section 4, we know the monopoly quality q_M is determined by $C^{'}(q_M) = 1/4$ and price p_M is set equal to $q_M/2$. Only half of the consumers in the market enjoy the information good and the total consumer surplus is $q_M/8$. The monopolist profit is $\Pi_M = q_M/4 - C(q_M)$. The total social welfare is $W_M(q_M) = 3q_M/8 - C(q_M)$.

The social optimal and monopoly, compared in Table 5, represent two extremes where the first focuses on social welfare while the second focuses on the firm profits. At the social optimal, quality, consumer surplus and total social welfare are the highest. The monopolist

Table 5. Comparison of Socially Optimal and Monopoly

	Socially Optimal	Monopoly
Quality	$C^{'}(q^O) = 1/2$	$C^{'}(q_M) = 1/4$
Price	0	$q_M/2$
Market Coverage	1	1/2
Consumer Surplus	$q^O/2$	$q_M/8$
Firm Profit	$-C(q^O)$	$q_M/4 - C(q_M)$
Total Social Welfare	$q^O/2 - C(q^O)$	$3q_M/8 - C(q_M)$

obtains its profit by serving only half of the market, and the monopolist earns the highest profit.

In a simultaneous move duopoly, given the same technology, firm A produces q_A which is higher than the monopoly q_M while firm B produces q_B which is lower than the monopoly q_M. The market coverage of q_A is more than 1/2 and the total market coverage is more than 3/4. The total profits of firm A and B are less but the total consumer surplus is higher than that of the monopoly. The social welfare is also higher than in monopoly. In the entry deterrence situation, if the leader accommodates entry, then it is equivalent to the simultaneous move duopoly. If the leader successfully deters entry, it acts like a monopolist. But in this case, the leader usually provides a higher quality than in monopoly without entry, and profits are lower. The consumer surplus is higher in the successful entry deterrence case and the market coverage is the same as in monopoly. In this situation, the social welfare cannot be determined without specifying a development cost function.

7 Conclusions

This paper focuses on the competition of vertically differentiated information goods. Under assumptions of linear utility function and convex development costs, we explain why leading producers usually dominate the market. First, we reproduce the basic prior result in our context whereby a monopolist does not version. Next show that under competition, producers always offer information goods with a better price-quality ratio than in monopoly and more of the market is covered. Moreover, in a simultaneous move duopoly neither of the producers version. However, in a sequential game the leader can set quality higher than in monopoly to deter entry from the high-end market, and implement versioning to deter entry from the low-end market. Thus, for versioning to occur requires that there be a sequential game, and that in this game it is profit maximizing for the leader to deter rather than accommodate entry.

In examining leader strategies to deter entry, although the sunk costs of development pose a credible threat to deter potential entry from the high-end market, it may not be profit maximizing since quality is set higher than it would be in monopoly. Nonetheless, it is always profit maximizing for the leader to implement versioning strategies to deter entry from the low-end market. However, for versioning to be effective, versioning must be implemented irrevocably because once the follower enters the low-end market, it is no longer optimal for the leader to maintain its lower quality version in the market. Thus, if the lower quality version can be removed, or priced as though it is dominated, then versioning is not a credible threat to deter entry from the low-end market. To make versioning a credible threat - that is, irrevocable, the leader must have some mechanism to tie its lower quality version good with its higher quality version to make the follower believe that the lower quality version good will not be withdrawn from the market post-entry. One suggested mechanism is for the leader to sign long term service contracts with consumers for all the sub-versions.

The key limitations of the paper lie in the functional form of consumers' utility and the distribution of consumers' types, which restricts the generality of our results. Our results rely on the assumptions that a consumer's utility is multiplicative in taste and quality, and that consumers are uniformly distributed in their individual taste for quality. Further research can generalize the utility function and consumers' distribution. In the meanwhile, there are two possible extensions for this paper. The first one is to consider network externality effect. In that case, the various degraded versions may not just act as a "signal" to deter entry, but effective means to maximize profit (Jing, 2002). The other extension is to consider temporal issues for the development and marketing of information goods: timing may have significant impact on the development costs and the consequent optimal price and quality choices of information goods producers.

8 References

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9 Appendix

Table 1. Summary of Key Notation

Symbol	Explanation
$U(q,\theta)$	Utility that consumer θ gets from information good with quality q
$C(q)$	Cost of developing information good with quality q
V	Cost of versioning an information good
$\Pi(\cdot)$	profit function of the firm
p	price level of the information good
q	quality of the information good
θ	consumer taste for quality
r	price-quality ratio
t	comparative quality ratio
M	monopolist
A,B	competing firms who enter the specific market
N	Nash Equilibrium point where $q_A > q_B$
N'	Nash Equilibrium point where $q_A < q_B$
S	Stackelberg point where $q_A > q_B$
S'	Stackelberg point where $q_A < q_B$

*We use superscripts for variables and subscripts for functions to indicate variables and relevant functional forms for firms in different settings.

Proof of Proposition 1

Using the envelope theorem, we can easily get $p_M/q_M = 1/2$. Substituting back into the profit function, we have $\Pi_M = q_M/4 - C(q_M)$. Based on the first order condition, we have

$C'(q_M) = 1/4$. For the monopolist to profitably launch the information good, we have $\Pi_M = q_M/4 - C(q_M) > 0$, thus we get $C(q_M)/q_M < 1/4$. So we have $C(q_M)/q_M < C'(q_M)$. $\square$

$\Pi_A(q_A, q_B)$ is concave in q_A and $\Pi_B(q_A, q_B)$ is concave in q_B.

Proof. From (4), take the second derivative of $\Pi_A(q_A, q_B)$ with respect to q_A, we have

$$\frac{\partial^2 \Pi_A(q_A, q_B)}{\partial q_A^2} = -\frac{8q_B^2(5q_A + q_B)}{(4q_A - q_B)^4} - C_A''(q_A) < 0$$

and

$$\frac{\partial^2 \Pi_B(q_A, q_B)}{\partial q_B^2} = -\frac{2q_A^2(8q_A + 7q_B)}{(4q_A - q_B)^4} - C_B''(q_B) < 0.$$

Thus we have $\Pi_A(q_A, q_B)$ is concave in q_A and $\Pi_B(q_A, q_B)$ is concave in q_B. $\square$

Should Firms Version?

Equilibrium Prices in Case I. From the first order conditions of (8) with respect to p_A^H and p_A^L, and of (9) with respect to p_B, we get the best response functions as follows,

$$2p_A^H - p_B = q_A^H - q_B,$$

$$-q_A^L p_B + 2q_B p_A^L = 0,$$

and

$$\left[q_B - q_A^L\right] p_A^H - 2\left[q_A^H - q_A^L\right] p_B + \left[q_A^H - q_B\right] p_A^L = 0.$$

Applying the Cramer's Rule, we have

$$\Lambda_1 = \begin{vmatrix} 2, & -1, & 0 \\ 0, & -q_A^L, & 2q_B \\ q_B - q_A^L, & -2\left[q_A^H - q_A^L\right], & q_A^H - q_B \end{vmatrix} = 2\left[4q_A^H q_B - q_A^H q_A^L - q_B^2 - 2q_B q_A^L\right] > 0$$

And we get the equilibrium prices for p_A^H, p_B and p_A^L as follows,

$$p_A^H = \left[q_A^H - q_B\right]\left[4q_A^H q_B - q_A^H q_A^L - 3q_B q_A^L\right]/\Lambda_1, \tag{15}$$

$$p_A^L = q_A^L \left[q_A^H - q_B\right]\left[q_B - q_A^L\right]/\Lambda_1 \tag{16}$$

and

$$p_B = 2q_B \left[q_A^H - q_B\right]\left[q_B - q_A^L\right]/\Lambda_1. \tag{17}$$

Equilibrium Prices in Case II. From the first order conditions of (10) with respect to p_A^H and p_A^L, and of (11) with respect to p_B, we get the best response functions as follows,

$$2p_A^H - 2p_A^L = q_A^H - q_A^L,$$

$$2p_A^L - p_B = q_A^L - q_B,$$

and

$$-q_B p_A^L + 2q_A^L p_B = 0.$$

Applying the Cramer's Rule, we have

$$\Lambda_2 = \begin{vmatrix} 2, & -2, & 0 \\ 0, & 2, & -1 \\ 0, & -q_B, & 2q_A^L \end{vmatrix} = 2\left[4q_A^L - q_B\right] > 0,$$

and we get the equilibrium prices for p_A^H, p_A^L and p_B as follows,

$$p_A^H = \left[4q_A^H q_A^L - q_A^H q_B - 3q_A^L q_B\right]/\Lambda_2, \tag{18}$$

$$p_A^L = 4q_A^L \left[q_A^L - q_B\right]/\Lambda_2 \tag{19}$$

and

$$p_B = 2q_B \left[q_A^L - q_B\right]/\Lambda_2. \tag{20}$$

Both firms consider versioning. Here we assume firm A develops its high quality version q_A^H and generates a lower version q_A^L, and firm B also develops its quality q_B and generates a lower version q_B^L. Prices p_A^H, p_A^L, p_B^H and p_B^L are set according to Bertrand competition. There are three cases:

Case 1: $q_A^L < q_B^L < q_B^H < q_A^H$. Let θ_A^H denote the consumer indifferent between buying q_A^H and q_B^H, θ_B^H denote the consumer indifferent between buying q_B^H and q_B^L, θ_B^L denote the consumer indifferent between buying q_B^L and q_A^L, θ_A^L denote the consumer indifferent between buying q_A^L and not buying. We have $\theta_A^H = \left[p_A^H - p_B^H\right] / \left[q_A^H - q_B^H\right]$, $\theta_B^H = \left[p_B^H - p_B^L\right] / \left[q_B^H - q_B^L\right]$, $\theta_B^L = \left[p_B^L - p_A^L\right] / \left[q_B^L - q_A^L\right]$, and $\theta_A^L = p_A^L / q_A^L$. The profit function of firm A is

$$\Pi_A(p_A^H, p_A^L) = p_A^H \left[1 - \frac{p_A^H - p_B^H}{q_A^H - q_B^H}\right] + p_A^L \left[\frac{p_B^L - p_A^L}{q_B^L - q_A^L} - \frac{p_A^L}{q_A^L}\right] - C_A(q_A^H) - V. \tag{21}$$

The profit function for firm B is

$$\Pi_B(p_B^H, p_B^L) = p_B^H \left[\frac{p_A^H - p_B^H}{q_A^H - q_B^H} - \frac{p_B^H - p_B^L}{q_B^H - q_B^L}\right] + p_B^L \left[\frac{p_B^H - p_B^L}{q_B^H - q_B^L} - \frac{p_B^L - p_A^L}{q_B^L - q_A^L}\right] - C_B(q_B^H) - V. \tag{22}$$

From the first order conditions of (21) with respect to p_A^H and p_A^L, we get the best response functions of firm A as follows,

$$2p_A^H - p_B^H = q_A^H - q_B^H, \tag{23}$$

and

$$-q_A^L p_B^L + 2q_B^L p_A^L = 0. \tag{24}$$

From the first order conditions of (22) with respect to p_B^H and p_B^L, we get the best response functions of firm B as follows,

$$\left[q_B^H - q_B^L\right] p_A^H - 2\left[q_A^H - q_B^L\right] p_B^H + 2\left[q_A^H - q_B^H\right] p_B^L = 0, \tag{25}$$

and

$$2\left[q_B^L - q_A^L\right] p_B^H - 2\left[q_B^H - q_A^L\right] p_B^L + \left[q_B^H - q_B^L\right] p_A^L = 0. \tag{26}$$

Solving p_A^H, p_A^L, p_B^H and p_B^L from (23), (24), (25) and (26), we get

$$p_A^H = 2\left[q_A^H - q_B^H\right]\left[4q_A^H q_B^L - q_A^H q_A^L - 3q_B^L q_A^L\right]/\Lambda_3, \tag{27}$$

$$p_A^L = 2q_A^L\left[q_A^H - q_B^H\right]\left[q_B^L - q_A^L\right]/\Lambda_3, \tag{28}$$

$$p_B^H = \left[q_A^H - q_B^H\right]\left[4q_B^H q_B^L - q_B^H q_A^L - 3q_B^L q_A^L\right]/\Lambda_3, \tag{29}$$

and

$$p_B^L = 4q_B^L\left[q_A^H - q_B^H\right]\left[q_B^L - q_A^L\right]/\Lambda_3. \tag{30}$$

Here $\Lambda_3 = \left[4q_A^H - q_B^H\right]\left[4q_B^L - q_A^L\right] - 9q_B^L q_A^L$.

Substituting the equilibrium prices as functions of quality back into the profit function of firm A, we have

$$\Pi_A(q_A^H, q_A^L) = \frac{4\left[q_A^H - q_B^H\right]}{\left[\Lambda_3\right]^2}\left[q_A^L q_B^L\left[q_A^H - q_B^H\right]\left[q_B^L - q_A^L\right] + \left[4q_A^H q_B^L - q_A^H q_A^L - 3q_B^L q_A^L\right]^2\right] - C_A(q_A^H) - V.$$

Taking the partial derivative of $\Pi_A(\cdot)$ with respect to q_A^L, we have

$$\frac{\partial \Pi_A(q_A^H, q_A^L)}{\partial q_A^L} = -\frac{4\left[q_B^L\right]^2\left[q_A^H - q_B^H\right]^2}{\left[\Lambda_3\right]^3}\left[80q_B^L\left[q_A^H - q_A^L\right] + 4q_A^L\left[q_A^H - q_B^H\right] + 3q_B^H\left[q_B^L - q_A^L\right] + q_B^L\left[q_B^H - q_A^L\right]\right].$$

Because $\Lambda_3 = 8q_B^L\left[q_A^H - q_A^L\right] + 4q_B^L\left[q_A^H - q_B^H\right] + 4q_A^H\left[q_B^L - q_A^L\right] + q_A^L\left[q_B^H - q_B^L\right] > 0$, we get

$$\frac{\partial \Pi_A(q_A^H, q_A^L)}{\partial q_A^L} < 0.$$

The negative sign comes from $q_A^L < q_B^L < q_B^H < q_A^H$, which means that increasing the quality of its lower version reduces firm A's profit. Consequently, it is not optimal for firm A to version its information good. When firm A chooses not to version, it is also not optimal for firm B to version.

Case 2: $q_B^L < q_A^L < q_B^H < q_A^H$**.** Let θ_A^H denote the consumer indifferent between buying q_A^H and q_B^H, θ_B^H denote the consumer indifferent between buying q_B^H and q_A^L, θ_A^L denote the consumer indifferent between buying q_A^L and q_B^L, θ_B^L denote the consumer indifferent between buying q_B^L and not buying. We have $\theta_A^H = \left[p_A^H - p_B^H\right] / \left[q_A^H - q_B^H\right]$, $\theta_B^H = \left[p_B^H - p_A^L\right] / \left[q_B^H - q_A^L\right]$, $\theta_A^L = \left[p_A^L - p_B^L\right] / \left[q_A^L - q_B^L\right]$, and $\theta_B^L = p_B^L / q_B^L$. The profit function of firm A is

$$\Pi_A(p_A^H, p_A^L) = p_A^H \left[1 - \frac{p_A^H - p_B^H}{q_A^H - q_B^H}\right] + p_A^L \left[\frac{p_B^H - p_A^L}{q_B^H - q_A^L} - \frac{p_A^L - p_B^L}{q_A^L - q_B^L}\right] - C_A(q_A^H) - V. \tag{31}$$

The profit function for firm B is

$$\Pi_B(p_B^H, p_B^L) = p_B^H \left[\frac{p_A^H - p_B^H}{q_A^H - q_B^H} - \frac{p_B^H - p_A^L}{q_B^H - q_A^L}\right] + p_B^L \left[\frac{p_A^L - p_B^L}{q_A^L - q_B^L} - \frac{p_B^L}{q_B^L}\right] - C_B(q_B^H) - V. \tag{32}$$

From the first order conditions of (31) with respect to p_A^H and p_A^L, we get the best response functions of firm A as follows,

$$2p_A^H - p_B^H = q_A^H - q_B^H, \tag{33}$$

and

$$\left[q_A^L - q_B^L\right] p_B^H - 2\left[q_B^H - q_B^L\right] p_A^L + \left[q_B^H - q_A^L\right] p_B^L = 0. \tag{34}$$

From the first order conditions of (32) with respect to p_B^H and p_B^L, we get the best response functions of firm B as follows,

$$\left[q_B^H - q_A^L\right] p_A^H - 2\left[q_A^H - q_A^L\right] p_B^H + \left[q_A^H - q_B^H\right] p_A^L = 0, \tag{35}$$

and

$$-q_B^L p_A^L + 2q_A^L p_B^L = 0. \tag{36}$$

Solving p_A^H, p_A^L, p_B^H and p_B^L from (33), (34), (35) and (36), we get

$$p_A^H = 2\left[q_A^H - q_B^H\right] \left\{q_A^H \left[q_B^H - q_A^L\right] \left[q_A^L - q_B^L\right] + 3q_A^L \left[q_A^H - q_A^L\right] \left[q_B^H - q_B^L\right]\right\} / \Lambda_4, \tag{37}$$

$$p_A^L = 2q_A^L \left[q_A^H - q_B^H\right] \left[q_B^H - q_A^L\right] \left[q_A^L - q_B^L\right] / \Lambda_4, \tag{38}$$

$$p_B^H = \left[q_A^H - q_B^H\right] \left[q_B^H - q_A^L\right] \left[4q_B^H q_A^L - q_B^H q_B^L - 3q_A^L q_B^L\right] / \Lambda_4, \tag{39}$$

and

$$p_B^L = q_B^L \left[q_A^H - q_B^H\right] \left[q_B^H - q_A^L\right] \left[q_A^L - q_B^L\right] / \Lambda_4. \tag{40}$$

Here $\Lambda_4 = 12q_A^L \left[q_A^H - q_A^L\right] \left[q_B^H - q_B^L\right] + 4\left[q_A^H - q_B^H\right] \left[q_B^H - q_A^L\right] \left[q_A^L - q_B^L\right] - 3q_B^L \left[q_B^H - q_A^L\right]^2 > 0$

.

Substituting the equilibrium prices as functions of quality back into the profit function of firm B, we have

$$\Pi_B(q_B^H, q_B^L) = \frac{\left[q_A^H - q_B^H\right] \left[q_B^H - q_A^L\right]}{\left[\Lambda_4\right]^2} \{q_A^L q_B^L \left[q_A^L - q_B^L\right] \left[q_A^H - q_B^H\right] \left[q_B^H - q_A^L\right]$$

$$+ \left[q_A^H - q_A^L\right] \left[4q_B^H q_A^L - q_B^H q_B^L - 3q_A^L q_B^L\right]^2\} - C_B(q_B^H) - V.$$

Taking the partial derivative of $\Pi_B(\cdot)$ with respect to q_B^L, we have

$$\frac{\partial \Pi_B(q_B^H, q_B^L)}{\partial q_B^L} = -\frac{\left[q_A^L\right]^2 \left[q_A^H - q_B^H\right]^2 \left[q_B^H - q_A^L\right]^2}{\left[\Lambda_4\right]^3} \{84q_A^L \left[q_A^H - q_A^L\right] \left[q_B^H - q_B^L\right]$$

$$-4\left[q_A^H - q_B^H\right] \left[q_B^H - q_A^L\right] \left[q_A^L - q_B^L\right] - 3q_B^L \left[q_B^H - q_A^L\right]^2\}.$$

Because $q_B^L < q_A^L < q_B^H < q_A^H$, we get

$$\frac{\partial \Pi_B(q_B^H, q_B^L)}{\partial q_B^L} < 0.$$

It means that increasing the quality of its lower version reduces firm B's profit. Consequently, it is not optimal for firm B to version its information good. When firm B chooses not to version, it is also not optimal for firm A to version.

Case 3: $q_B^L < q_B^H < q_A^L < q_A^H$. Let θ_A^H denote the consumer indifferent between buying q_A^H and q_A^L, θ_A^L denote the consumer indifferent between buying q_A^L and q_B^H, q_B^H denote the consumer indifferent between buying q_B^H and q_B^L, θ_B^L denote the consumer indifferent between buying q_B^L and not buying. We have $\theta_A^H = \left[p_A^H - p_A^L\right] / \left[q_A^H - q_A^L\right]$, $\theta_A^L = \left[p_A^L - p_B^H\right] / \left[q_A^L - q_B^H\right]$, $\theta_B^H = \left[p_B^H - p_B^L\right] / \left[q_B^H - q_B^L\right]$, and $\theta_B^L = p_B^L / q_B^L$.

The profit function for firm B is

$$\Pi_B(p_B^H, p_B^L) = p_B^H \left[\frac{p_A^L - p_B^H}{q_A^L - q_B^H} - \frac{p_B^H - p_B^L}{q_B^H - q_B^L}\right] + p_B^L \left[\frac{p_B^H - p_B^L}{q_B^H - q_B^L} - \frac{p_B^L}{q_B^L}\right] - C_B(q_B^H) - V. \tag{41}$$

From the first order conditions of (41) with respect to p_B^L, we get

$$\frac{p_B^H - p_B^L}{q_B^H - q_B^L} = \frac{p_B^L}{q_B^L}, \tag{42}$$

which means that $\theta_B^H = \theta_B^L$ and there is no market for q_B^L. So it is not optimal for firm B to version its information good. When firm B chooses not to version, it is also not optimal for firm A to version. $\square$

Proof of Proposition 3

In the text we show that the leader providing a high quality good decreases its quality in a Stackelberg game. Here we show in detail that the leader providing a low quality good increases its quality in a Stackelberg game. This is the case when $q_A < q_B$.

From (5), we can get Π_A as

$$\Pi_A(q_A, q_B) = q_A q_B \left[q_B - q_A\right] / \left[4q_B - q_A\right]^2 - C_A(q_A),$$

and we have

$$\frac{\partial \Pi_A(q_A, q_B)}{\partial q_B} = \frac{q_A^2 \left[q_A + 2q_B\right]}{\left[4q_B - q_A\right]^3} > 0. \tag{43}$$

From (6), the best response function $q_B(q_A)$ is determined by

$$C_B'(q_B) = 4q_B \left[4q_B^2 - 3q_A q_B + 2q_A^2\right] / \left[4q_B - q_A\right]^3 .$$

If firm A increases q_A, $C_B'(q_B)$ increases, and so does q_B. Thus, we derive from the best response function that $dq_B/dq_A > 0$.

At the Stackelberg point

$$\frac{\partial \Pi_A(q_A, q_B(q_A))}{\partial q_A} + \frac{\partial \Pi_A(q_A, q_B(q_A))}{\partial q_B}\frac{dq_B}{dq_A} = 0,$$

and we have $\partial \Pi_A(q_A, q_B(q_A))/\partial q_B > 0$ and $dq_B/dq_A > 0$, then $\partial \Pi_A(q_A, q_B(q_A))/\partial q_A < 0$.

We know at the Nash equilibrium point, $\partial \Pi_A(q_A, q_B)/\partial q_A = 0$. From our analysis of the simultaneous game, we know at the Nash equilibrium, $\partial \Pi_A(q_A, q_B)/\partial q_A = 0$. Denoting the Stackelberg quality provided by the leader as $q_A^{S'}$ and the Nash equilibrium quality as $q_A^{N'}$, from the concavity of $\Pi_A(q_A, q_B)$ in q_A we have $q_A^{S'} > q_A^{N'}$. It means with first mover advantage, the leader that provides low quality good increases its quality to increase its profit. $\square$

Entry Deterrence with Versioning.

i) If $q_A^D \leq q_M$, then the leader can safely deter entry at q_M and get the optimal profits. Versioning is implemented and the follower is out of the market.

ii) If $q_M < q_A^D < q_A^{DI}$, then the leader cannot deter entry at q_M. It is still optimal for the leader to deter entry and obtain monopoly profits because she still gets more profits than if she chooses to accommodate entry, which is $\Pi_M(q_A^D) > \Pi_A(q_A^{S'}, q_B^{S'})$. The optimal quality of the information good provided by the leader is thus q_A^D. Versioning is implemented and the follower is out of the market.

iii) If $q_M < q_A^{DI} \leq q_A^D$, then the leader is better off accommodating entry because the optimal profits she gets from entry deterrence are less than if she chooses to produce at $q_A^{S'}$ to accommodate entry, which is $\Pi_M(q_A^D) < \Pi_A(q_A^{S'}, q_B^{S'})$. The optimal quality of the information good provided by the leader is thus $q_A^{S'}$. The corresponding quality of good by the follower is $q_B^{S'}$. No versioning is implemented. $\square$

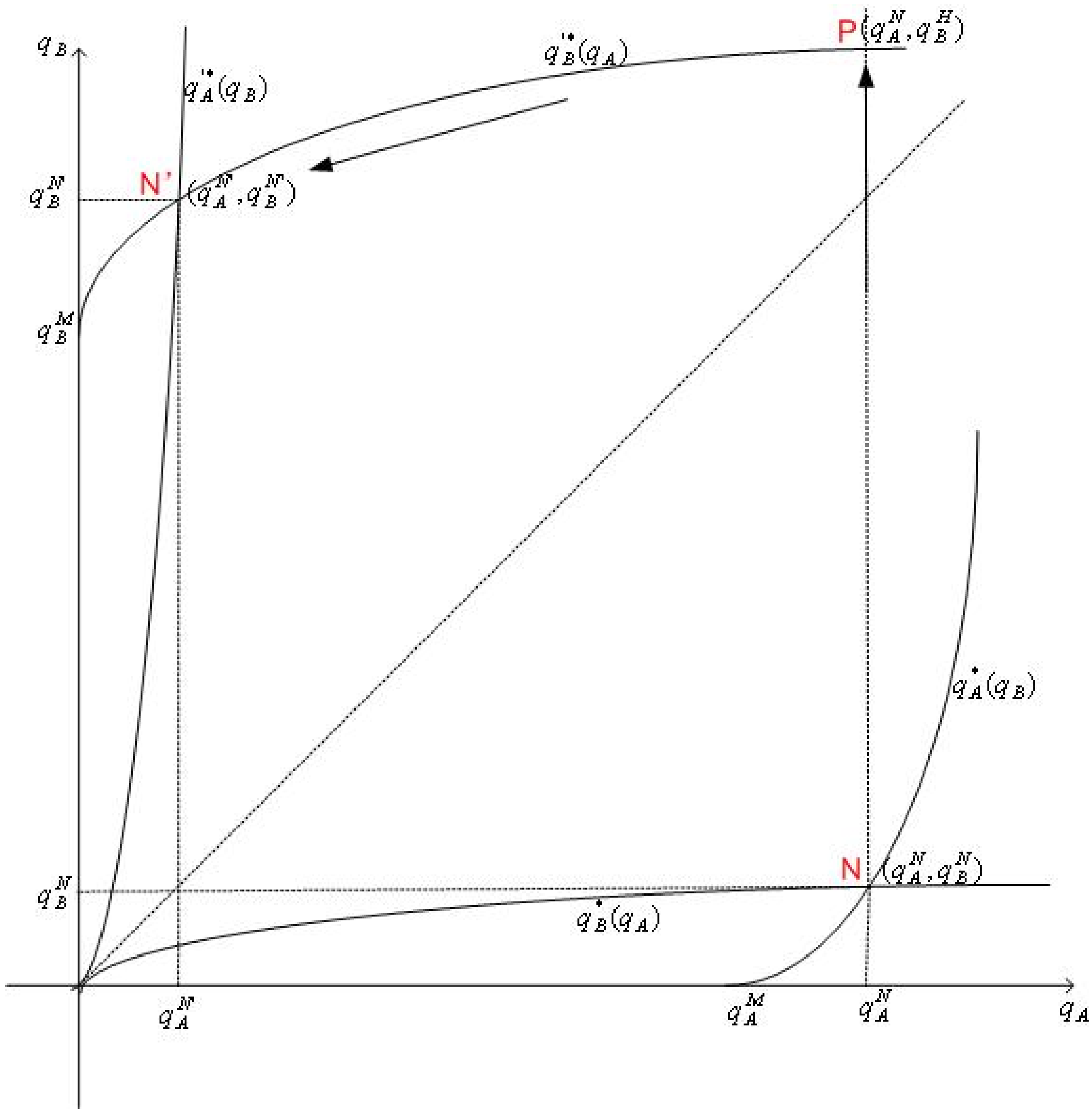

Diagram 1: Two Nash Equilibria in the Simultaneous Game

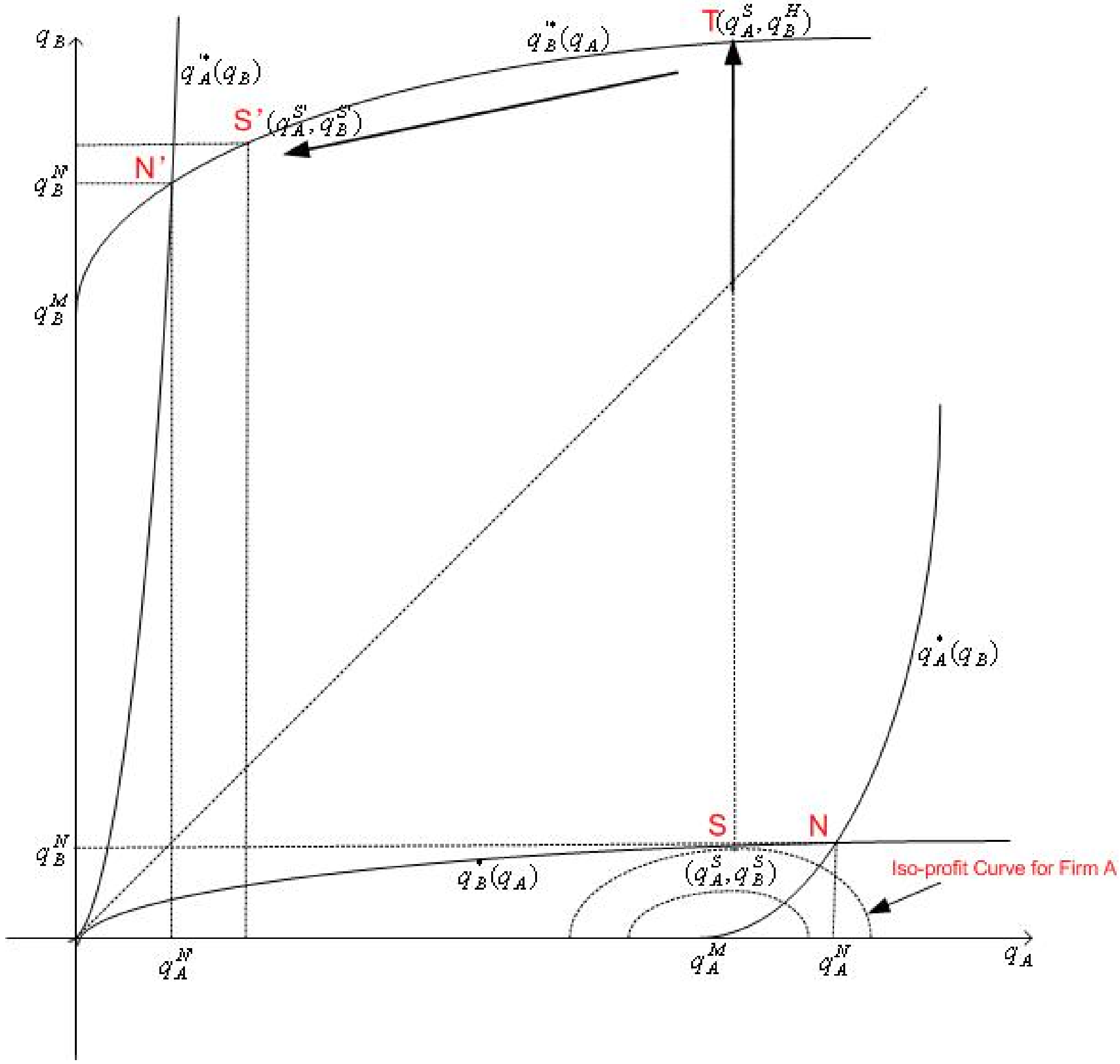

Diagram 2: A Stackelberg Game Solution