Vertically Differentiated Information Goods: Entry Deterrence, Rivalry Clear-out or Coexistence

(Student-Authored Paper)

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Abstract

In this paper we develop models to analyze price, quality and versioning strategies of information goods producers to deter entry and maintain market power. We find that in a competitive environment, firms provide higher quality information goods with a better "price quality ratio" than in a monopoly. In the high-end market an incumbent monopolist can strategically set its quality to deter entry. In the low-end market, the incumbent monopolist can implement versioning strategies to deter entry and different versions exist as a signal to prevent potential entry. A vertically differentiated market is often referred to as a "natural oligopoly" for traditional goods, whereas it can be regarded as a "natural monopoly" for information goods.

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

1 Introduction

Characterized by large sunk costs of development, and by negligible costs of reproduction and distribution, information goods show substantial economies of scale (Shapiro and Varian, 1999). Jones and Mendelson (2005) categorize information goods as: i) computer software including operation systems, programming tools and applications; ii) online services such as internet search engines and portals; iii) online content such as information provided by Lexis/Nexis, Dow Jones, and Reuters; and iv) other digitalized information goods such as digitalized music, movies and books. An additional unit of an information good can be produced and distributed at negligible cost by allowing it to be downloadable over the Internet (Jones and Mendelson, 2005). Broad adoption of e-commerce, secure and convenient online payments and high-speed internet connections greatly lower the transaction costs.

Another notable feature of information goods is that after the highest quality version of the information good has been developed, the development of its vertically degraded versions is usually less costly. Versioning is to "offer a product line and let users choose the version of the product most appropriate for them (Shapiro and Varian, 1999)", which is often referred to as "the second degree price discrimination". Developments in software engineering have made versioning of most computer software virtually cost-free. Thus, information goods producers can easily provide vertically differentiated products, thereby segmenting the market to maximize profit (Wei and Nault, 2005). Hahn (2001) investigates the functional quality degradation of software and shows that "the functional quality degradation is an effective consumer screening device, especially when consumers' valuation for each function is negatively correlated". Bhargava and Choudhary (2005) reach a similar conclusion under more general settings about consumer heterogeneity and utility functions.

With the ease of versioning, product differentiation and pricing strategies of information goods are different from traditional goods, especially in the context of competition. Leading producers of information goods usually have substantial market power. As of 2002, Microsoft Windows controlled 97.46% of the global desktop operation systems market (Windows IT Pro, 2002). Oracle's market share on Linux was 80.6% in 2005, up from 76.1% in 2004 and its revenues in the fast growing Linux market were up 95% in 2005 (www.oracle.com). According to the Nielsen cabinet, as the most popular search engine on the web, Google had a market share of 54% in 2006, ahead of Yahoo! (23%) and MSN (13%) (www.google.com, 2006). Competition for information goods is more intense than traditional goods and the winners usually dominate the market. Meanwhile, with potential competition, producers of information goods have an incentive to improve quality. They launch their highest quality version, or upgrade the old version, whenever possible, even if they lose money at the margin by cannibalizing the existing market share of the old version (Nault and Vandenbosch, 1996). It is also common for the software producers to release a buggier product early and patch it later to grab the "first mover advantage" in the market (Arora, Caulkins, and Telang, 2006). The subsequent questions are: 1) why do leading producers of information goods dominate their market? and, 2) why is a monopoly producer so eager to improve the quality of its information goods under potential competition?

To address the above questions, this paper proposes a duopoly model to analyze the optimal price and quality choices for information goods, and discusses the effectiveness of implementing versioning strategies to deter entry in the competitive environment. We find that in a competitive environment firms always provide higher quality information goods with a better "price quality ratio" than in a monopoly. In the high-end market an incumbent monopolist can strategically set its quality to deter entry. In the low-end market, the incumbent monopolist can effectively implement versioning strategies to deter entry and different versions exist as a signal to prevent potential entry. A vertically differentiated market is often referred to as a "natural oligopoly" for traditional goods (Shaked and Sutton, 1983), whereas it can be regarded as a "natural monopoly" for information goods.

2 Literature Review

There is broad literature in the research of price discrimination, product differentiation and market segmentation. Frank, Massy and Wind (1972) propose a model of third degree price discrimination which assumes market segments are isolated and consumers from one segment cannot purchase goods from another segment. Moorthy (1984) investigates on consumer self-selection and proposes product line design strategies based on second degree price discrimination. By using consumer self-selection, consumers choose between products in different market segments based on their valuation for the product. Product differentiation becomes the focus for firms to implement price discrimination. Pricing of products designed for different market segments are related with each other, and cannibalization occurs between different market segments. Moorthy and Png (1992) further address market cannibalization using timing as an effective way to reduce cannibalization when consumers are relatively more impatient than the seller. For most information goods distributed through Internet, consumer self-selection is the only choice for firms deciding their pricing strategies. Recent literature has focused on effective methods in dealing with market cannibalization and optimal product line design.

Price discrimination and product differentiation are common ways this problem has been addressed. Vertical differentiation and pricing strategies are modeled in different contexts such as network externalities (Jing, 2002), competition (Jones and Mendelson, 2005) and anti-piracy (Wu, Chen and Anandalingam, 2003). They all reach the conclusion that vertical differentiation is not optimal without certain constraints, consistent with Bhargava and Choudhary (2001). Bhargava and Choudhary (2005) examine nonlinear utility functions for information goods and propose that vertical differentiation is optimal when lower type consumers have greater ratios of valuations than higher type consumers. Lilien, Kotler and Moorthy (1992) recognized that vertical differentiation would be attractive when consumers were sufficiently heterogeneous because versions could differentiate users. Bakos and Brynjolfsson (1999) studied the strategy of bundling information goods and found that bundling large numbers of unrelated information goods can be profitable, but when different market segments of consumers differ systematically in their valuations for goods, simple bundling is no longer optimal. Sundararajan (2004) showed that with information goods fixed-fee and usage-based pricing can be used together to maximize firm profits.

Competition with information goods has been the focus of additional research. Nault (1997) examined quality differentiation using inter-organizational information systems (IOS) and found that IOS could effectively differentiate consumers and reduce competition in duopoly. Dewan, Jing and Seidmann (2003) developed a duopoly model where firms could produce both standard products and customized products. They found that "when firms face a fixed entry cost and adopt customization sequentially, the first entrant always achieves an advantage and may be able to deter subsequent entry by choosing its customization scope strategically" (Dewan, et. al, 2003). Choudhary, Ghose, Mukopadhyay and Rajan (2005) proposed a personalized pricing (PP) strategy where firms produced vertically differentiated goods and could perfectly identify valuations of heterogenous consumers. They found that "while PP results in a wider market coverage, it also leads to aggravated price competition between firms" (Choudhary, et. al 2005).

Empirical research has also been conducted to investigate product and pricing strategies. Nault and Dexter (1995) found that with the adoption of a specific IT system - the cardlock system in a commercial fueling company, successfully differentiated its product and maintained a premium between $5-12\%$ of retail price of the fuel commodity. Cottrell and Nault (2004) analyzed product variety and scope economies in the microcomputer software industry and found that 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. Ghose, Smith and Telang (2005) empirically analyzed the degree to which used products cannibalize new product sales for books and its welfare impact using a dataset collected from Amazon.com's new and used book marketplaces. They found that used books are poor substitutes for new books for most of Amazon's customers, but the existence of used book marketplace increases consumer surplus and total welfare. Ghose and Sundararajan (2005) estimated the extent of quality degradation associated with software versioning using a 7-month, 108-product panel of software sales from Amazon.com and 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, which is consistent with the theory of vertical differentiation.

In this paper, we analyze the quality and price choices of the information goods producers under monopoly and duopoly. We set up our notation and assumptions in section 3, analyze the monopoly environment in section 4, and examine a simultaneous move duopoly environment in section 5. In section 6, we discuss the sequential move duopoly environment and entry deterrence strategies. We further compare different situations where firms choose their optimal strategy among entry deterrence, rivalry clear-out or coexistence. Social welfare implications in different situations are analyzed in section 7. Discussion and future research are included in section 8.

3 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 1. Consumers select their favorite good to maximize their consumer surplus $U(q, \theta) - p$, where p is the price of the good. Denoting quality as $q \in [0, +\infty)$, 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, 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. This is our second assumption:

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

Denoting different quality versions with subscripts, after the highest quality q_H of the information good is produced, firm may degrade it to generate a lower quality version q_L. We assume versioning costs are negligible compared with the development cost, effectively setting versioning costs to zero. This is our third assumption:

Assumption 3 *Versioning costs are zero after the highest quality information good is 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 their profit. This and notation used later are summarized in Table 1.

4 A Monopoly Model

We assume the monopolist provides N versions of the information good with quality levels $Q = (q^1, q^2, \ldots, q^{N-1}, q^N)$. Without loss of generality, we assume $q^1 > q^2 > \ldots > q^{N-1} > q^N$. The highest quality q^1 is developed first, and the subsequent degraded qualities $q^2, \ldots, q^{N-1}, q^N$ are produced through versioning. Let $P = (p^1, p^2, \ldots, p^{N-1}, p^N)$ denote the relevant prices for the above quality levels, and $D(P, q^i)$ denotes the demand for the good

Table 1. Summary of Key Notation

Symbol	Explanation
$U(q, \theta)$	Utility that consumer type θ gets from information good with quality level q
$C(q)$	Cost function of developing information good with quality level q
$\Pi(.)$	profit function of the firm
p	price level of the information good
q	quality level of the information good
θ	consumer type
k	price quality ratio
t	comparative quality ratio
M	monopoly firm
A,B	firms who enter the specific market simultaneously
I	incumbent firm
E	potential entrant firm

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

with quality q^i given the price set P. The monopolist chooses quality levels and prices to maximize profit. The profit function for the monopolist is

$$\Pi(P(Q), Q) = \sum_{i=1}^{N} p^i D(P, q^i) - C(q^1).$$

The provision of N different quality levels divides the target market into $N + 1$ segments, where the last segment is when consumers do not purchase. In market segment i where the consumer only chooses between buying the good designed for her segment and not buying, we define θ^i as the indifferent consumer and the price assignment is

$$p^i = U(q^i, \theta^i).$$

In the market segment i where the consumer chooses between buying the good q^i and a good q^j designed for another segment j, we define θ^i as the indifferent consumer type and the price assignment is

$$p^i = p^j + U(q^i, \theta^i) - U(q^j, \theta^i).$$

In a vertically differentiated market, indifferent consumer types only exist between two contiguous segments. Using the price assignments the indifferent consumer type is defined by $\theta^i = (p^i - p^{i+1})/(q^i - q^{i+1})$, for $i = \{1, 2, \ldots, N-1\}$, and $\theta^N = p^N/q^N$. Consumers in market segment $[\theta^1, 1]$ buy good with quality q^1, consumers in $[\theta^i, \theta^{i-1}), i = \{2, \ldots, N\}$ buy versions with quality q^i, and consumers in $[0, \theta^N)$ do not buy. The profit maximization problem of the monopolist can be rewritten as

$$\max_{P(Q),Q} \Pi = p^1(1 - \frac{p^1 - p^2}{q^1 - q^2}) + \sum_{i=2}^{N-1} p^i(\frac{p^{i-1} - p^i}{q^{i-1} - q^i} - \frac{p^i - p^{i+1}}{q^i - q^{i+1}}) + p^N(\frac{p^{N-1} - p^N}{q^{N-1} - q^N} - \frac{p^N}{q^N}) - C(q^1)$$

$$\ni p^1 > p^2 > \ldots > p^N;\ q^1 > q^2 > \ldots > q^N.$$

The first term in the above profit function indicates revenue generated from version q^1, the second term indicates revenue generated from versions $q^2, \cdots, q^{N-1}$, the third term indicates revenue generated from version q^N. The last term indicates development cost for version q^1. For the optimal prices and qualities P and Q, using the envelope theorem, we have $\partial\Pi(P(Q), Q)/\partial P = 0$. Thus we have

$$\frac{p^1 - p^2}{q^1 - q^2} = \frac{p^2 - p^3}{q^2 - q^3} = \ldots = \frac{p^{N-1} - p^N}{q^{N-1} - q^N} = \frac{p^N}{q^N} = \frac{1}{2},$$

meaning that all the indifferent consumer types are equal. Therefore, except for segment 1, the demand for all the other market segments is zero. It indicates that a profit maximizing monopolist only provides one version. This result is consistent with the findings of Jones and Mendelson (1998), Bhargava and Choudhary (2001) and basic argument of Jing (2001), and Wu, Chen and Anandalingam (2003).

We denote the optimal price and quality of the only version by p^M and q^M, respectively. The optimal "price quality ratio" is denoted by $k^M = p^M/q^M$. We have the following proposition:

Proposition 1:

1. *An information good monopolist provides only one version.*

2. *The necessary condition for a monopolist to profitably launch the information good is that the marginal cost of developing the information good is greater than the average cost of the development.*

3. *The optimal "price quality ratio" of the information good provided by the monopolist is* $1/2$.

All the proofs are in the Appendix. The monopolist does not cover the market. Although the optimal price quality ratio of the information good provided by the monopolist is $1/2$, if the price quality ratio is less than $1/2$, then more of the market is covered and the market is fully covered when the "price quality ratio" is zero. If the price quality ratio is greater than $1/2$, then less of the market is covered and the market fails when the price quality ratio is greater than 1.

5 Simultaneous Move Duopoly

We now examine the case where two firms A and B are both in the market. Each firm develops their version quality based on the quality level of the other firm. The information goods are assumed to be vertically differentiated. In the appendix we provide detailed proof that it is profit maximizing for either firm to provide only one version of the information good. Each firm also signals its proposed quality level of the good to each other. After the information goods are produced, both firms choose prices according to Bertrand competition. Consumers choose their preferred goods based on the qualities and prices of the information goods.

The duopoly model is thus a typical two stage game:

- Stage 1: Firm A and B develop information goods with quality levels q^A and q^B.
- Stage 2: Both firms compete in prices.

We consider pure strategy SPNE (subgame perfect Nash equilibrium) of this game. If both firm develop information goods with the same quality level, Bertrand competition drives prices to zero, which is not an SPNE. Without loss of generality, we suppose $q^A > q^B$. The costs 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 to be the same.

Let θ^A denote consumer type which is indifferent between buying goods of quality q^A and q^B, and θ^B denote consumer type which is 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. For firm A the profit function is expressed as

$$\Pi_A(p^A, q^A) = p^A(1 - \frac{p^A - p^B}{q^A - q^B}) - C_A(q^A). \tag{1}$$

Using the first order condition with respect to p^A to get the best response function of firm A we have[1]

$$2p^A - p^B = q^A - q^B. \tag{2}$$

For firm B the profit function is expressed as

$$\Pi_B(p^B, q^B) = p^B(\frac{p^A - p^B}{q^A - q^B} - \frac{p^B}{q^B}) - C_B(q^B).$$

Using the first order condition with respect to p^B to get the best response function of firm B we have

$$p^A/(2p^B) = q^A/q^B. \tag{3}$$

[1] The sufficient second order conditions are satisfied for (1) and the remaining optimization problems. Details are available upon request.

Solving (2) and (3),

$$p^A = 2q^A(q^A - q^B)/(4q^A - q^B) \tag{4}$$

and

$$p^B = q^B(q^A - q^B)/(4q^A - q^B). \tag{5}$$

The equilibrium price quality ratio of good provided by firm A is denoted by $k^A = p^A/q^A$ and the equilibrium price quality ratio of good provided by firm B is denoted by $k^B = p^B/q^B$. We also denote the "comparative quality ratio" by t where $t = q^A/q^B$. Since $q^A > q^B$, we have $t > 1$. Thus, the solutions for p^A and p^B in (4) and (5) can be rewritten as

$$k^A = 2(t-1)/(4t-1) \tag{6}$$

and

$$k^B = (t-1)/(4t-1). \tag{7}$$

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 $k^A < 1/2$ and $k^B < 1/4$. It is not surprising that both firms provide goods with better price quality ratio than that of the monopolist.

From (4) and (5) 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 $\theta^A - \theta^B = t/(4t-1) > 1/4$. It indicates that the low quality firm B has a market share of exactly a half of firm A. The total market served is more than 3/4. Therefore, the total market served expands more than 50 percent in duopoly competition.

Stage 1. Substituting (4) and (5) back into the profit functions of firms A and B, we have

$$\Pi_A(q^A, q^B) = 4(q^A)^2(q^A - q^B)/(4q^A - q^B)^2 - C_A(q^A)$$

and

$$\Pi_B(q^A, q^B) = q^A q^B(q^A - q^B)/(4q^A - q^B)^2 - C_B(q^B).$$

Firms A and B choose quality levels q^A and q^B to maximize their profits, thus we have $\partial\Pi_A/\partial q^A = 0$ and $\partial\Pi_B/\partial q^B = 0$. The equilibrium quality levels q^A and q^B are determined by

$$C'_A(q^A) = 4t(4t^2 - 3t + 2)/(4t - 1)^3$$

and

$$C'_B(q^B) = t^2(4t - 7)/(4t - 1)^3.$$

For $t > 1$, we have $C'_A(q^A) > 1/4$ and $C'_B(q^B) < 1/16$. If all the firms have the same technology, $C_A(q) = C_B(q)$, then we have $q^B < q^M < q^A$. This means that the high quality firm produces a higher quality information good in a duopoly than a monopolist.

To summarize the above, we have the following proposition:

Proposition 2:

1. *It is profit maximizing for either firm to provide only one version of the information good.*

2. *With the same technology, the high quality firm in duopoly competition produces an information good with higher quality than a monopolist.*

3. *Both firms provide information goods with better price quality ratios in duopoly competition than in monopoly.*

4. *In duopoly competition, the high quality firm has exactly twice as much market share as the low quality firm. The total market share expands more than* 50 *percent than the monopoly firm.*

6 Sequential Move and Entry Deterrence

In this section we show that in a sequential duopoly game, the first mover can strategically set the quality level of the information good to deter entry from the high-end market while implementing a versioning strategy to deter entry from the low-end market.

6.1 Entry Deterrence from the High-end Market

In a sequential game, the incumbent firm I first develops an information good at quality level q^I and sets price p^I. The potential entrant determines whether to enter the information good market or not. If entry is profitable, the entrant firm E determines its optimal quality level q^E to develop and sets price p^E according to Bertrand competition. Consumers choose their preferred goods after the qualities and prices of the information goods are determined.

In this sub-section we analyze potential entry from the high-end market, which means that the entrant develops quality $q^E > q^I$. Once entry occurs, the equilibrium prices of both firms are determined in the same manner as in the simultaneous game. We still denote the comparative quality ratio here by $t = q^E/q^I$. Thus, we have the equilibrium prices as before except with incumbent and entrant labelling

$$p^E = 2q^E(t-1)/(4t-1)$$

and

$$p^I = q^I(t-1)/(4t-1).$$

The profits of both firms are

$$\Pi_E(q^E, q^I) = q^E(4t(t-1)/(4t-1)^2 - C_E(q^E)/q^E) \tag{8}$$

and

$$\Pi_I(q^E, q^I) = q^I(t(t-1)/(4t-1)^2 - C_I(q^I)/q^I). \tag{9}$$

From the first order condition of (8), the equilibrium quality level q^E is determined by

$$C'_E(q^E) = 4t(4t^2 - 3t + 2)/(4t - 1)^3 \tag{10}$$

From (10), we get $C'_E(q^E)$ is decreasing with t. Thus, if the incumbent firm I strategically sets its initial quality level q^I higher, then t decreases and the optimal q^E increases. We notice that when t decreases and q^E increases, in the profit function Π_E, the first part $4t(t-1)/(4t-1)^2$ decreases while the second part $C_E(q^E)/q^E$ increases. The incumbent firm I can strategically set its initial quality level q^I such that the profit of entrant from the high-end market equals to zero. The strategic quality level q^I is determined by

$$C_E(q^E)/q^E = 4t(t-1)/(4t-1)^2$$

where we set the optimal profit of the entrant firm E as 0, and

$$C'_E(q^E) = 4t(4t^2 - 3t + 2)/(4t - 1)^3.$$

which is exactly equation (10) that determines the equilibrium quality level q^E.

We notice that the optimal entry deterrence quality level of the incumbent is dependent on the development cost function of the potential entrant. From discussions in this section, we derive the following proposition.

Proposition 3:

1. *The incumbent firm can strategically set its quality to deter entry from the high-end market.*

2. *The entry deterrence quality level of the information good is never lower than that in monopoly.*

3. *With the same technology of developing an information good, incumbent can always profitably deter entry.*

We recognize that entry deterrence may not be consistent with profit maximization. When entry deterrence is consistent with profit maximization, the information good producer can be well regarded as a "natural monopoly". But usually they are not the same. In order to effectively deter entry, the incumbent firm may have to sacrifice its profit. Under certain conditions entry deterrence may even incur negative profit for the incumbent firm. In the appendix we discuss those conditions in more detail.

However, for some strategic considerations such as the "top dog strategy" that overinvestment makes the incumbent tougher (Fudenberg and Tirole, 1984), the incumbent firm may still choose to overinvest in development to deter entry. If the incumbent firm has sunk its development cost for entry deterrence quality level q^I, then the enhanced q^I is always a credible threat to the potential entrant. The effect of the excess investment in the development of the information good is equivalent to the excess capacity investment in Dixit's model of entry deterrence where "the threat of a predatory output increase after entry is made credible by carrying excess capacity prior to entry" (Dixit, 1980).

6.2 Entry Deterrence from the Low-end Market

When the incumbent strategically sets its quality at a higher level to deter entry from the high-end market, it opens another door to the potential entrant - entry may occur from the low-end market.

Under the strategic quality level q^I determined in the previous sub-section, without versioning strategies, potential entrant firm determines its optimal quality q^E to enter the low-end market by

$$C_E'(q^E) = (q^I)^2(4q^I - 7q^E)/(4q^I - q^E)^3.$$

The optimal profit for the entrant is

$$\Pi_E(q^E) = q^E q^I(q^I - q^E)/(4q^I - q^E)^2 - C_E(q^E).$$

If $\Pi_E(q^E) \leq 0$, then entry is deterred. Otherwise, we may consider a versioning strategy to deter entry from the low-end market. In this sub-section, we propose a model where the incumbent strategically degrades its high quality information good to generate a low quality version to deter entry from the low-end market.

In the model setting, the incumbent has already developed its high quality version q_H^I. It generates a low quality version q_L^I in order to deter entry from the low-end market. The potential entrant determines whether to enter the information good market or not. If entry is profitable, the entrant determines its optimal quality level q^E, and prices p^E, p_H^I and p_L^I are set according to the Bertrand competition. Consumers select their preferred goods after the qualities and prices of the information goods are determined.

In this model we assume $q_L^I < q^E < q_H^I$.[2] In this situation, let θ_H^I denote the consumer type which is indifferent between buying information goods q_H^I and q^E, θ^E denote the consumer type which is indifferent between buying information goods q^E and q_L^I, and θ_L^I denote the consumer type which is indifferent between buying information good q_L^I and not buying. Similar to the analysis earlier, we have $\theta_H^I = (p_H^I - p^E)/(q_H^I - q^E)$, $\theta^E = (p^E - p_L^I)/(q^E - q_L^I)$, and $\theta_L^I = p_L^I/q_L^I$.

The profit function Π_I for the incumbent firm is expressed as

$$\Pi_I(p_H^I, p_L^I, q_H^I, q_L^I) = p_H^I(1 - \frac{p_H^I - p^E}{q_H^I - q^E}) + p_L^I(\frac{p^E - p_L^I}{q^E - q_L^I} - \frac{p_L^I}{q_L^I}) - C_I(q_H^I). \tag{11}$$

And the profit function Π_E for the entrant is expressed as

$$\Pi_E(p^E, q^E) = p^E(\frac{p_H^I - p^E}{q_H^I - q^E} - \frac{p^E - p_L^I}{q^E - q_L^I}) - C_E(q^E). \tag{12}$$

From the first order conditions of equation (11) with respect to p_H^I and p_L^I, and of equation

[2]One might argue that potential entry may come from even lower-end market, which means $q^E < q_L^I$. In that case, incumbent firm can generate another lower version to deter entry, with the same mechanism as discussed in this sub-section.

(12) with respect to p^E, we get the best reponse functions as following,

$$\begin{cases} 2p_H^I & -p^E & & = q_H^I - q^E \\ & -q_L^I p^E & +2q^E p_L^I & = 0 \\ (q^E - q_L^I)p_H^I & -2(q_H^I - q_L^I)p^E & +(q_H^I - q^E)p_L^I & = 0 \end{cases}$$

Applying the Cramer's Rule, we have

$$\Lambda = \begin{vmatrix} 2, & -1, & 0 \\ 0, & -q_L^I, & 2q^E \\ q^E - q_L^I, & -2(q_H^I - q_L^I), & q_H^I - q^E \end{vmatrix} = 2(4q_H^I q^E - q_H^I q_L^I - (q^E)^2 - 2q^E q_L^I)$$

We get the equilibrium prices for p_H^I, p^E and p_L^I as following

$$p_H^I = (q_H^I - q^E)(4q_H^I q^E - q_H^I q_L^I - 3q^E q_L^I)/\Lambda$$

and

$$p^E = 2q^E(q_H^I - q^E)(q^E - q_L^I)/\Lambda$$

and

$$p_L^I = q_L^I(q_H^I - q^E)(q^E - q_L^I)/\Lambda.$$

We notice that if $q^E = q_L^I$, then the equilibrium prices $p^E = p_L^I = 0$ and $p_H^I = (q_H^I - q^E)/2$. It indicates that firm with information good of higher quality can always drive the rival out of the market by generating a sub-version of the same quality. Bertrand competition drives prices of the low quality information goods down to zero.

We denote the comparative quality ratio of q_H^I, q^E with respect to q_L^I by $t^H = q_H^I/q_L^I$ and $t^E = q^E/q_L^I$. The optimal price quality ratio of versions q_H^I and q_L^I provided by firm I are denoted by $k^H = p_H^I/q_H^I$ and $k^L = p_L^I/q_L^I$, respectively. The optimal price quality ratio of versions q^E provided by firm E is denoted by $k^E = p^E/q^E$. From the equilibrium prices equations, we get

$$k^H = \frac{(t^H - t^E)(4t^E - 1 - 3t^E/t^H)}{2(4t^H t^E - t^H - 2t^E - (t^E)^2)}$$

and

$$k^E = \frac{(t^H - t^E)(t^E - 1)}{(4t^H t^E - t^H - 2t^E - (t^E)^2)}$$

and

$$k^L = \frac{(t^H - t^E)(t^E - 1)}{2(4t^H t^E - t^H - 2t^E - (t^E)^2)}.$$

From the above equations, we have $k^E = 2k^L$ and $k^H > 2k^E$. It indicates that the equilibrium price quality ratio of version q_H^I is more than four times that of the low quality version q_L^I offered by the same firm I.

Substituting the equilibrium prices back into the profit function for the firm I and E, we have

$$\Pi_I(q_H^I, q^E, q_L^I) = \frac{(q_H^I - q^E)}{\Lambda^2}[(4q_H^I q^E - q_H^I q_L^I - 3q^E q_L^I)^2 + q^E q_L^I (q_H^I - q^E)(q^E - q_L^I)] - C_I(q_H^I)$$

and

$$\Pi_E(q_H^I, q^E, q_L^I) = \frac{4(q^E)^2(q_H^I - q^E)(q_H^I - q_L^I)(q^E - q_L^I)}{\Lambda^2} - C_E(q^E).$$

Taking the partial derivative of Π_E with respect to q_L^I, we have,

$$\frac{\partial \Pi_E(q_H^I, q^E, q_L^I)}{\partial q_L^I} = \frac{-8(q^E)^2(q_H^I - q^E)^2}{\Lambda^3}(2q_H^I q^E + q_H^I q_L^I + (q^E)^2 - 4q^E q_L^I) < 0.$$

It means the higher the quality level q_L^I of the sub-version, the lower the profit of the potential entrant E. Therefore, the incumbent firm I can strategically set the quality level q_L^I of the sub-version to deter entry.

In order to effectively deter entry, q_L^I must be set so that $\Pi_E(q^E) \leq 0$. Through the envelope theorem, we have $\partial \Pi_E(q^E)/\partial q^E = 0$. Thus, the strategic quality level of the low quality version q_L^I is determined by

$$C_E(q^E)/q^E = \frac{4(q^E)(q_H^I - q^E)(q_H^I - q_L^I)(q^E - q_L^I)}{\Lambda^2}$$

and

$$C'_E(q^E) = \frac{8q^E(q^I_H - q^I_L)}{\Lambda^3}[q^I_H(q^I_H - q^E)(4(q^E)^2 + 2(q^I_L)^2 - 3q^E q^I_L) \\ +q^E q^I_L(q^E - q^I_L)(2q^E + q^I_H) - 3(q^E)^3(q^I_H - q^I_L)].$$

Again, the optimal entry deterrence quality level of the sub-version depends on the development cost function of the potential entrant.

We also notice that

$$\frac{\partial \Pi_I(q^I_H, q^I_L)}{\partial q^I_L} = \frac{-2(q^E)^2(q^I_H - q^E)^2}{\Lambda^3}(20q^I_H q^E + q^I_H q^I_L + (q^E)^2 - 22q^E q^I_L) < 0.$$

This inequality means that increasing the quality of the sub-version also lower the profit of the incumbent firm. This is equivalent to "the lean and hungry look" effect referred to by Fudenberg and Tirole (1984) where the incumbent firm underinvests to accommodate entry. If the entrant has already entered from the low-end market, it is never optimal for the incumbent to version its information good.

If the incumbent firm can adjust its price to respond to entry very quickly and can convey this behavior credibly to the potential entry, once the incumbent firm successfully deters entry, it can remain as a monopolist in the information good market. In that case, as we discussed earlier, the monopolist sells only the highest version. Different versions can be developed by the incumbent and sold in limited range. These versions exist as a signal to deter potential entry. In this perspective, it is always profit maximizing to generate the sub-version to deter entry when versioning costs are negligible compared with the development costs. The following proposition concludes this sub-section.

Proposition 4:

1. *The incumbent firm can strategically degrade its high quality information good to generate a low quality version to deter entry from the low-end market.*

2. *If the entrant already entered from the low-end market, it is never optimal for the incumbent firm to version its information good.*

3. *The entry deterrence strategy in the low-end market is always consistent with the incumbent's profit maximizing strategy.*

4. *In the entry deterrence situation, versioning functions as signal rather than profit maximizing method.*

6.3 Entry Deterrence, Rivalry Clear-out or Coexistence

We know from the previous discussion that the incumbent can strategically develop information goods at higher quality level to deter entry from the high-end market and generate versions to deter entry into the low-end market. The key questions here are: i) Is the threat a credible one to deter entry? ii)Is it worthwhile for the incumbent to deter entry? iii) If rivalry already exists in the market, is it profit maximizing for one firm to drive its competitor out? If the answer of any of the above questions is "no", then firms may choose to coexist with its competitors.

Rivalry Clear-out & Coexistence. We first consider the case where firms A and B are already in the market with information goods q^A and q^B. Without loss of generality, we suppose $q^A > q^B$. Since the development costs are sunk and there is no marginal cost, a firm will not exit the market if the price of its good is greater than zero. From section 5, we know that in equilibrium, profits for firm A and B are

$$\Pi_A(q^A) = 4(q^A)^2(q^A - q^B)/(4q^A - q^B)^2 - C_A(q^A)$$

and

$$\Pi_B(q^B) = q^A q^B(q^A - q^B)/(4q^A - q^B)^2 - C_B(q^B).$$

Obviously, firm B with a lower quality information good cannot drive firm A with a high quality good out of the market. For firm A to drive out firm B, it can generate a lower quality version with quality which is exactly q^B and set its price at zero, which is the equilibrium price according to the Bertrand competition. From discussion in the previous section, we know the equilibrium profit for firm B is zero and profit for firm A is

$$\Pi_A(q^A, q^B) = (q^A - q^B)/4 - C_A(q^A)$$

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 $\Pi_A(q^A, q^B) < \Pi_A(q^A)$. Therefore, firm A is better off coexisting with firm B.

Entry Deterrence & Coexistence. We now compare profits under entry deterrence and coexistence. From discussion in the previous section, we know it is always profit maximizing for the incumbent to generate a lower quality version to deter entry from the low-end market. However, versioning is not a credible threat to the potential entry. If entrant actually enters the market, it is profit maximizing for the incumbent to withdraw the lower quality version and only sell the highest version. To make versioning a credible threat, the incumbent must have some mechanism to tie the lower quality version with its higher quality version.

In the high-end market, the sunk costs of development pose a credible threat to deter potential entry. However, the entry deterrence strategy may not be consistent with the profit maximizing strategy. As we discussed previously, if entry is allowed from the high-end market, the optimal quality level for the incumbent is q^B and the optimal quality level for the entrant is q^A as discussed in section 5 and the relevant profit of the incumbent is denoted by $\Pi_I^D(q^A, q^B)$. We have $\Pi_I^D(q^A, q^B) = q^A q^B (q^A - q^B)/(4q^A - q^B)^2 - C_I(q^B)$. If entry is deterred with optimal entry deterrence quality level q^I and the incumbent behaves as a monopoly, the relevant profit of the incumbent is denoted by $\Pi_I^M(q^I)$. From discussions in section 4, we have $\Pi_I^M(q^I) = q^I/4 - C_I(q^I)$. And we have:

- If $\Pi_I^M(q^I) \geq \Pi_I^D(q^A, q^B)$, then the entry deterrence strategy is consistent with the profit maximizing strategy. It is profit maximizing for the incumbent firm to strategically set its quality to deter entry from the high-end market.

- If $\Pi_I^M(q^I) < \Pi_I^D(q^A, q^B)$, then the entry deterrence strategy is not consistent with the profit maximizing strategy. It is profit maximizing for the incumbent firm to accommodate entry.

As we mentioned in proposition 2, with the same technology for developing an information good, incumbent can always profitably deter entry. Thus, for the potential entrant, it must have superior cost advantage in developing information good to enter the market.[3]

7 Welfare Implications

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

In a monopoly, the optimal price p^M and quality q^M are determined to maximize the profit of the firm. From section 4, we know q^M are 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 gains profit $\Pi_M = q^M/4 - C(q^M)$. The total social welfare is $W_M(q^M) = 3q^M/8 - C(q^M)$.

[3] Applying a timing game model, Nault and Vandenbosch (2000) introduce the concept of "disruptive technologies" to explain entry in next generation information technology markets.

Table 2. Comparison of Socially Optimal and Monopoly

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

The social optimal and the monopoly represent two extreme situation where the first focuses on social welfare while the second focuses on the firm profits. The Table 2 shows the comparison of these two situations.

From the comparison, we see that the socially optimal quality, consumer surplus and total social welfare are higher than those of monopoly. Actually, at the social optimal, quality, consumer surplus and total social welfare are the highest among all situations we discuss in the paper. The monopolist obtains its optimal profit by serving only half of the market. In all the situations, the monopolist obtains the highest profit.

In the simultaneous move of the duopoly case, 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 total social welfare is also higher than that in the monopoly. In the entry deterrence situation, if the incumbent firm I chooses to accommodate entry, then it is equivalent to the simultaneous move of the duopoly case. If the incumbent firm successfully deters entry, it acts like a monopolist. But in this case, the incumbent firm usually provide quality level q^I which is higher than the monopoly q^M. So the profit of producing q^I is less than that of the monopolist who produces q^M. The consumer surplus is higher in the successful entry deterrence case and the market coverage is the same as the monopoly case. In this situation, the total social welfare cannot be determined without specifying a development cost function.

8 Conclusions

This paper focuses on analysis of the competition of vertically differentiated information goods. Under assumptions of linear utility function and convex development costs, we explain why competition of information goods is so intense that leading producers usually dominate the market. We have shown that under competition, producers always offer information goods with better "price quality ratio" than in a monopoly and the market is better covered as well. Although in a simultaneous move duopoly game neither of the producers versions their relevant information goods, in a sequential game the incumbent firm can strategically set the quality level of the information good to deter entry from the high-end market while implementing a versioning strategy to deter entry from the low-end market.

We further show that although the sunk costs of development pose a credible threat to deter potential entry from the high-end market, it may not be consistent with the profit maximizing strategy. It is always profit maximizing for the incumbent to implement versioning strategies to deter entry from the low-end market and different versions exist as a signal to prevent potential entry. However, versioning is not a credible threat to the potential entrant. To make versioning a credible threat, the incumbent must have some mechanism to tie its lower quality version good with its higher quality version to make the potential entrant believe that the lower quality version good will not be withdrawn from the market in the post-entry situation. Social welfare is also discussed according to different situations and we find that consumer surplus is always better under competition (including potential competition) than in a monopoly.

The limitations of the paper lie in the functional form of consumers' utility and the distribution of consumers' types. 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 the information goods producers.

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10 Appendix

Proof of Proposition 1

We already show that in the monopoly environment, only one version is provided. Using the envelope theorem, it is easy to get $K^M = p^M/q^M = 1/2$. Substitute back to the profit function, we have $\Pi = q^M/4 - C(q^M)$. Based on the first order condition, we have $C'(q^M) = 1/4$. For the monopolist to profitably launch the information good, we have $\Pi = q^M/4 - C(q^M) > 0$, thus we get $C(q^M)/q^M < 1/4$. So we have $C(q^M)/q^M < C'(q^M)$. Q.E.D.

Proof of Proposition 2

Without loss of generality, we suppose the highest quality produced by firm A is higher than that by firm B.

Situation I. We first discuss the situation when firm A considers versioning. In this situation we assume firm A develops its high quality version q_H^A and degrade it generate a lower version q_L^A. Firm B determines its optimal quality level q^B to develop and prices p^B, p_H^A and p_L^A are set according to the Bertrand competition. There are two cases in this situation:

Case 1: $q_L^A < q^B < q_H^A$.

Let θ_H^A denote consumer type which is indifferent between buying information goods q_H^A and q^B, θ^B denote consumer type which is indifferent between buying information goods q^B and q_L^A, and θ_L^A denote consumer type which is indifferent between buying information good q_L^A

and not buying. We have $\theta_H^A = (p_H^A - p^B)/(q_H^A - q^B)$, $\theta^B = (p^B - p_L^A)/(q^B - q_L^A)$, and $\theta_L^A = p_L^A/q_L^A$.

The profit function Π_A for firm A is expressed as

$$\Pi_A(p_H^A, p_L^A, q_H^A, q_L^A) = p_H^A(1 - \frac{p_H^A - p^B}{q_H^A - q^B}) + p_L^A(\frac{p^B - p_L^A}{q^B - q_L^A} - \frac{p_L^A}{q_L^A}) - C_A(q_H^A). \tag{13}$$

And the profit function Π_B for firm B is expressed as

$$\Pi_B(p^B, q^B) = p^B(\frac{p_H^A - p^B}{q_H^A - q^B} - \frac{p^B - p_L^A}{q^B - q_L^A}) - C_B(q^B). \tag{14}$$

From the first order conditions of equation (13) with respect to p_H^A and p_L^A, and of equation (14) with respect to p^B, we get the best reponse functions as following,

$$\begin{cases} 2p_H^A & -p^B & & = q_H^A - q^B \\ & -q_L^A p^B & +2q^B p_L^A & = 0 \\ (q^B - q_L^A)p_H^A & -2(q_H^A - q_L^A)p^B & +(q_H^A - q^B)p_L^A & = 0 \end{cases}$$

Applying the Cramer's Rule, we have

$$\Lambda_1 = \begin{vmatrix} 2, & -1, & 0 \\ 0, & -q_L^A, & 2q^B \\ q^B - q_L^A, & -2(q_H^A - q_L^A), & q_H^A - q^B \end{vmatrix} = 2(4q_H^A q^B - q_H^A q_L^A - (q^B)^2 - 2q^B q_L^A)$$

And we get the equilibrium prices for p_H^A, p^B and p_L^A as following

$$p_H^A = (q_H^A - q^B)(4q_H^A q^B - q_H^A q_L^A - 3q^B q_L^A)/\Lambda_1$$

and

$$p^B = 2q^B(q_H^A - q^B)(q^B - q_L^A)/\Lambda_1$$

and

$$p_L^A = q_L^A(q_H^A - q^B)(q^B - q_L^A)/\Lambda_1.$$

Substitute the equilibrium prices back into the profit function for firm A, we have

$$\Pi_A(q_H^A, q^B, q_L^A) = \frac{(q_H^A - q^B)}{(\Lambda_1)^2}[(4q_H^A q^B - q_H^A q_L^A - 3q^B q_L^A)^2 + q^B q_L^A (q_H^A - q^B)(q^B - q_L^A)] - C_A(q_H^A)$$

Take partial derivative of Π_A with respect to q_L^A, we have,

$$\frac{\partial \Pi_A(q_H^A, q^B, q_L^A)}{\partial q_L^A} = \frac{-2(q^B)^2(q_H^A - q^B)^2}{(\Lambda_1)^3}(20q_H^A q^B + q_H^A q_L^A + (q^B)^2 - 22q^B q_L^A) < 0.$$

It means that increasing the quality of the sub-version lowers the profit of the incumbent firm. Obviously when $q_L^A = 0$, $\Pi_A(q_H^A, q^B, q_L^A) = \Pi_A(q_H^A, q^B)$. To maximize its profit, firm A sets $q_L^A = 0$. So it is not optimal for firm A to version its information good.

Case 2: $q^B < q_L^A < q_H^A$**.**

Let θ_H^A denote consumer type which is indifferent between buying information goods q_H^A and q_L^A, θ_L^A denote consumer type which is indifferent between buying information goods q_L^A and q^B, and θ^B denote consumer type which is indifferent between buying information good q^B and not buying. We have $\theta_H^A = (p_H^A - p_L^A)/(q_H^A - q_L^A)$, $\theta_L^A = (p_L^A - p^B)/(q_L^A - q^B)$, and $\theta^B = p^B/q^B$.

The profit function Π_A for firm A is expressed as

$$\Pi_A(p_H^A, p_L^A, q_H^A, q_L^A) = p_H^A(1 - \frac{p_H^A - p_L^A}{q_H^A - q_L^A}) + p_L^A(\frac{p_H^A - p_L^A}{q_H^A - q_L^A} - \frac{p_L^A - p^B}{q_L^A - q^B}) - C_A(q_H^A). \tag{15}$$

And the profit function Π_B for firm B is expressed as

$$\Pi_B(p^B, q^B) = p^B(\frac{p_L^A - p^B}{q_L^A - q^B} - \frac{p^B}{q^B}) - C_B(q^B). \tag{16}$$

From the first order conditions of equation (15) with respect to p_H^A and p_L^A, and of equation (16) with respect to p^B, we get the best reponse functions as following,

$$\begin{cases} 2p_H^A & -2p_L^A & & = q_H^A - q_L^A \\ & 2p_L^A & -p^B & = q_L^A - q^B \\ & -q^B p_L^A & +2q_L^A p^B & = 0 \end{cases}$$

Applying the Cramer's Rule, we have

$$\Lambda_2 = \begin{vmatrix} 2, & -2, & 0 \\ 0, & 2, & -1 \\ 0, & -q^B, & 2q_L^A \end{vmatrix} = 2(4q_L^A - q^B)$$

And we get the equilibrium prices for p_H^A, p_L^A and p^B as following

$$p_H^A = (4q_H^A q_L^A - q_H^A q^B - 3q_L^A q^B)/\Lambda_2$$

and

$$p_L^A = 4q_L^A(q_L^A - q^B)/\Lambda_2$$

and

$$p^B = 2q^B(q_L^A - q^B)/\Lambda_2.$$

Substitute the equilibrium prices back into the profit function for firm A, we have

$$\Pi_A(q_H^A, q_L^A, q^B) = \frac{16q_H^A q_L^A(q_L^A - q^B) + q^B(q_H^A - q_L^A)(8q_L^A + q^B)}{(\Lambda_2)^2} - C_A(q_H^A)$$

Take partial derivative of Π_A with respect to q_L^A, we have,

$$\frac{\partial \Pi_A(q_H^A, q_L^A, q^B)}{\partial q_L^A} = \frac{2(q^B)^2(20q_L^A + q^B)^2}{(\Lambda_2)^3} > 0.$$

It means that increasing the quality of the sub-version increases the profit of the incumbent firm. Obviously when $q_L^A = q_H^A$, $\Pi_A(q_H^A, q^B, q_L^A) = \Pi_A(q_H^A, q^B)$. To maximize its profit, firm A sets $q_L^A = q_H^A$. So it is still not optimal for firm A to version its information good.

Situation II. Then we discuss the situation when firm B considers versioning. In this situation we assume firm A and B develop their highest quality version q^A and q_H^B, respectively. Firm B degrades q_H^B to generate a lower version q_L^B. We have $q_L^B < q_H^B < q^A$. Prices p^A, p_H^B and p_L^B are set according to the Bertrand competition.

Let θ^A denote consumer type which is indifferent between buying information goods q^A and q_H^B, θ_H^B denote consumer type which is indifferent between buying information goods q_H^B and q_L^B, and θ_L^B denote consumer type which is indifferent between buying information good q_L^B and not buying. We have $\theta^A = (p^A - p_H^B)/(q^A - q_H^B)$, $\theta_H^B = (p_H^B - p_L^B)/(q_H^B - q_L^B)$, and $\theta_L^B = p_L^B/q_L^B$.

The profit function Π_A for firm A is expressed as

$$\Pi_A(p^A, q^A) = p^A(1 - \frac{p^A - p_H^B}{q^A - q_H^B}) - C_A(q^A). \tag{17}$$

And the profit function Π_B for firm B is expressed as

$$\Pi_B(p_H^B, p_L^B, q_H^B, q_L^B) = p_H^B(\frac{p^A - p_H^B}{q^A - q_H^B} - \frac{p_H^B - p_L^B}{q_H^B - q_L^B}) + p_L^B(\frac{p_H^B - p_L^B}{q_H^B - q_L^B} - \frac{p_L^B}{q_L^B}) - C_B(q_H^B). \tag{18}$$

From the first order conditions of equation (18) with respect to p_L^B, we get

$$\frac{p_H^B - p_L^B}{q_H^B - q_L^B} = \frac{p_L^B}{q_L^B}$$

It is equivalent that $\theta_H^B = \theta_L^B$! There is no market for q_L^B. So it is not optimal for firm B to version its information good.

The above discussion can be easily extended to the cases when firm A and firm B consider generating multi-versions. Thus we conclude that it is profit maximizing for either firm to provide only one version of the information good in duopoly. Q.E.D.

Proof of Proposition 3

Based on the development cost function $C_E(.)$ and the marginal cost function $C'_E(.)$, we can derive the strategic quality level q^I of the incumbent firm to deter entry. When entry is successfully deterred, the incumbent firm can behave as a monopoly. It can set the price at $q^I/2$ to maximize its profit. If $q^I < q^M$, then incumbent can further set $q^I = q^M$ to improve its profit while still deterring entry. Thus we get the entry deterrence quality level of the information good is never lower than that in the monopoly environment.

As we discussed in the paper, if entry is allowed from the high-end market, the optimal quality level for the incumbent is q^B and the optimal quality level for the entrant is q^A as discussed in section 5 and the relevant profit of the incumbent is denoted by $\Pi_I^D(q^A, q^B)$. We have $\Pi_I^D(q^A, q^B) = q^B(t(t-1)/(4t-1)^2 - C_B(q^B)/q^B)$, where $t = q^A/q^B$. If entry is deterred with optimal entry deterrence quality level q^I and the incumbent behaves as a monopoly, the relevant profit of the incumbent is denoted by $\Pi_I^M(q^I)$. From discussions in section 4, we have $\Pi_I^M(q^I) = q^I/4 - C_I(q^I)$. If the incumbent and the entry adopt the same technology, we have $C_I(q^I)/q^I < C_I(q^E)/q^E = C_E(q^E)/q^E < 1/4$ since $q^I < q^E$, thus we get $\Pi_I^M(q^I) > 0$. It means with the same technology of developing an information good, incumbent can always profitably deter entry.

- If $\Pi_I^M(q^I) < \Pi_I^D(q^A, q^B)$, then the entry deterrence strategy is not consistent with the profit maximizing strategy.
- If $\Pi_I^M(q^I) < 0$, then entry deterrence incurs negative profit for the incumbent firm. Q.E.D.