



MARKET ENTRY, PRODUCT QUALITY AND PRICE COMPETITION

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Abstract:

We study an entrant firm's product quality choice and the price competition arising between the entrant and the incumbent firm. We show that the entrant firm should introduce a relatively higher (lower) quality than the incumbent firm when the consumers' valuation for quality is sufficiently large (small). We also study how the incumbent firm modifies its price in response to the ensuing price competition. We find that the incumbent firm should decrease its price. We also profile how the incumbent firm's price non-linearly depends on consumers' valuation for quality.

Key words: *Market entry; quality, pricing, marketing, strategy, competition*

1. Introduction

When seeking to enter a new market, an entrant has to decide how it is to position itself to compete effectively with the current incumbent. For instance, should it introduce a relatively higher or lower quality product than the incumbent? Also, the incumbent firm needs to decide how to modify its price in response to the increased competition.

This issue has strong managerial relevance. For example, consider the pharmaceutical industry. The patent for Pfizer's blockbuster cholesterol-reducing drug Lipitor, expired on November 30, 2011 (CNN, Nov 2011). This prompted market entry by Ranbaxy and Watson and subsequently also by other drug manufacturers. They introduced generic drugs that had the same chemical composition as Lipitor (atorvastatin), but at a lower price. In response, Pfizer was forced to cut the price of Lipitor to compete with the generics. The price of a 10mg tablet of Lipitor was reduced from approximately \$3.36 to \$2.89 (Wall Street Journal, May 2012). Moreover, patients

with medical insurance saw their copayments for Lipitor drop from \$25 to \$10 per month (CBS News, 2011). Even when the ingredients were labelled as identical, consumers perceived the product quality of the newly introduced generic brand to be lower than the incumbent Lipitor. While the generic drug was positioned as a cheaper alternate, the erstwhile patent-protected incumbent was observed to reduce its price. Similarly, in the case of Johnson and Johnson. Their Tylenol brand had been a leading nonprescription analgesic brand in the US market. After their competitor Bristol-Myers introduced the Datriil brand as a low-priced alternative, J&J response was to reduce the price of Tylenol by 30% (Kalra et al 1998).

Such trends are also seen in other industries. For example, consider the market for sports drinks. Gatorade has been a leading brand. When Coca-Cola introduced PowerAde as an alternative to Gatorade, it led to Gatorade engaging in price wars with PowerAde (BrandWeek, July 1993). In general, this theme is common across many industries.

A pertinent issue is that entrants need to decide what product quality they should offer. When should they challenge the incumbent firm by introducing a relatively superior quality product and advertise this superior quality to steal the incumbent's best customers and gain market share? And when should they enter the market with a relatively lower quality product in order to scrape the barrel by stealing the incumbent's most price sensitive customers? Such strategic questions are commonly faced by entrants. Consider another example. Technological advances frequently lead to newer and superior products being introduced. The Google Chrome browser was introduced in Feb 2011 as a faster and better browser than the well-established incumbent, Microsoft Internet Explorer.

Given this background, the research questions explored in this paper are as follows:

- When should an entrant introduce a relatively higher (lower) quality product than the incumbent?
- How do the entrant's product quality and price depend on market forces, particularly consumers' valuation?
- How should the incumbent modify its price in response to the entrant? How does this decision change depending on whether the entrant is the quality leader or the quality laggard?

In order to address the above questions, we present a stylized two-period model. During the first time period, the incumbent is a monopolist, selling a product of unit quality at the profit-maximizing monopoly price. At the beginning of the second time period, a competitor enters the market. This entrant determines its price and product quality, which may be relatively more than or less than the quality of the incumbent. Simultaneously, the incumbent responds to the competitive entry by revising its period 1 price. Note that the incumbent is unable to modify its product quality in period 2. There is Bertrand price competition in the second period, with both firms individually maximizing total profits.

We find that the entrant introduces a relatively higher (lower) quality product than the incumbent's unit quality, if the range of consumers' valuation for quality is relatively large (small). Moreover, the entrant's quality and price are both increasing in consumers' valuation for quality. We also find that, as expected, the incumbent lowers its price in the second time period compared to its first-period price, in response to the loss of monopoly power and the increased price competition. The incumbent's second period price exhibits a counter-intuitive, inverted-U shaped response to an increase in consumers' marginal valuation for quality.

Lay intuition suggests that even in period 2, the incumbent should increase its price as consumers' valuation for quality increases. Consistent with intuition, when the extent of quality differentiation between the entrant and incumbent is relatively large, the incumbent's price is indeed increasing in consumers' valuation for quality. However, when this quality differentiation is relatively small, we find the opposite trend -- the incumbent's price is decreasing in consumers' valuation for quality.

The rest of this paper is organized as follows. In Section 2, we review the related literature. In Section 3, we present a two-period model of price competition between an incumbent and an entrant. We analyse the model to answer the research questions outlined above. We discuss our findings and conclude our paper in Section 4.

2. Literature Review

This paper is related to streams of research related to product quality and market entry. We review each strand of literature briefly, citing some seminal papers.

2.1 Product Quality in Monopoly

We review the product quality decision in a monopoly framework, originally developed by Mussa and Rosen (1978), Katz (1984), and Moorthy (1984) and subsequently summarized by Desai (2001). Moorthy (1984) considers a monopolist serving multiple consumer segments differing in their valuations for quality. Higher valuation segments derive greater marginal utility from quality, and hence are willing to pay a higher price for a given quality product than lower-valuation segments. It is optimal for the monopolist to create multiple products (price-quality bundles) so that higher-valuation consumers buy higher-quality products at higher prices. He explains that lower-quality products can potentially cannibalize higher-quality products and thereby undermine the segmentation. In order to limit cannibalization, optimal price-quality bundles are such that only the highest-valuation segment gets its preferred quality. The qualities of products aimed at all other segments are distorted downwards. Mussa and Rosen (1978) derive similar insights in a model with a continuous distribution of consumer valuations.

2.2 Product Quality under Competition

Gabszewicz and Thisse (1979) study oligopolies in which firms sell products of different qualities. They show that price competition can yield equilibrium market outcomes where some consumers do not buy anything or outcomes where all consumers buy one of the two products. The degree of product differentiation and the consumers' heterogeneity determine the outcome. In a seminal paper, Shaked and Sutton (1982) further investigate the question of competing firms setting products of different qualities. Building on this, Moorthy (1988) considers quality choice in a duopoly, assuming a quadratic cost function for quality with incomplete market coverage. Subsequently, Choi and Shin (1992) show that the lower quality firm will choose a quality level which is a fixed proportion of the higher quality firm's choice. Wauthy (1996) further reviews this literature.

Behavioural researchers have also studied the influence of quality perceptions and competition on marketing instruments. Recent examples include Cardinali and Bellini (2014) and Roest and Rindfleisch, (2010).

2.3 Market Entry

This paper is also related to prior research on market entry and market pioneers. Prior research shows there can be significant first-mover advantage. Previous research has found that a first mover could benefit from being recognized as the industry standard (Carpenter and Nakamoto 1989); a first-mover could also preempt competition by introducing wider product lines (Prescott and Visscher 1977) and benefit from the presence of a significant number of risk averse consumers (Schmalensee 1982). However, first movers can suffer disadvantages when a second mover free rides on the incumbent's investments or leverages a change in either technology or consumer needs (Lieberman and Montgomery 1988). Singh et al (2006) study the impact of a Wal-Mart supercentre entry on sales of a traditional supermarket. This is relevant to our work since Wal-Mart typically offers lower quality of customer service than traditional supermarkets.

Theoretical research on this topic indicates a diminishing marginal impact for later entrants. It is well-established that as the number of brands in a market increases, it becomes increasingly difficult for a new brand to enter a consumer's consideration set (Hauser and Wernerfelt 1990). Prescott and Visscher's (1977) demonstrate that the opportunity to serve an important unmet consumer need declines as the number of brands increases. Prior research has also analysed relative first and second mover advantages in duopoly games. This has been done by comparing the payoffs of two competing firms in the two sequential games of perfect information obtained by considering both orders of moves (Gal-Or 1985). Recently, Shen (2014) investigates the optimal entry and exit behavior of firms as an industry evolves.

It is worth noting that prior research has investigated our research topic using complementary research methodologies. For example, Karakaya and Yannopoulos

(2001) investigate the impact of market entrant characteristics on incumbents using Conjoint Analysis. Stasch and Ward (1997) analyse over 40 case studies to study competing marketing strategies when defending market leadership. Also, Topol et al. (1995) qualitatively study entry barriers in retailing.

3. Model

3.1 Firms

A market has two firms called the incumbent and the entrant, labelled $\{I, E\}$ respectively. There are two time periods. In Period 1, the incumbent I is a monopoly. It sells a product of quality q_I for a price p_{I1} . At the beginning of Period 2, the entrant E introduces a competing product of quality q_E for a price p_{E2} . At the same time, the incumbent modifies its price to p_{I2} . The incumbent is unable to modify its quality in Period 2, although it can modify its price.

The “quality” can be thought of simply as an attribute (or collection of attributes) that consumers always prefer more of for the same price. Since we are interested in the entrant’s strategic quality choice relative to the incumbent’s pre-existing fixed quality, we normalize the incumbent’s quality $q_I = 1$ and let $q_E = q$ denote the entrant’s quality choice decision. The entrant may choose to become the *quality laggard* by setting its quality to be less than the incumbent ($q < 1$). Alternately, the entrant may become the *quality leader*, by setting its quality to be relatively more than the incumbent ($q > 1$).

3.2 Cost

The firms obviously incur production costs. As one would expect, it is increasingly more costly to develop higher quality products. To model this, we assume that the cost is increasing and convex in the quality-level. Specifically, the marginal cost of producing a product of quality q_j is given by the production function $c_j[q_j, \gamma_j] = \gamma_j q_j^n$, where $\gamma_j > 0$ is a measure of the efficiency of the production technology and n is a measure of the convexity of the cost. The larger the γ_j , the lower is the production efficiency. For analytical tractability, we solve for $n = 2$. Our analysis generally applies whenever the cost function is sufficiently convex ($n \geq 2$). We assume that the production efficiency of the entrant and the incumbent are the same $\gamma_I = \gamma_E = \gamma$. This is because our objective is to understand the strategic interaction between the entrant’s quality choice and the incumbent and we wish to avoid outcomes that are generated merely by asymmetries in the production technology between the incumbent and the entrant. The fixed costs are assumed to be constant and are normalized to zero. Relaxing this assumption does not qualitatively change our insights. To summarize, the cost of production of the incumbent and entrant are $c_I = \gamma$ and $c_E = \gamma q^2$ respectively.

3.3 Consumers

The market is composed of a unit mass of consumers in each time period. All consumers prefer higher quality over lower quality, but they are heterogeneous in their willingness to pay for quality. The marginal valuation for quality, θ , of consumers in each time period is distributed uniformly on $\theta \sim [0, \alpha]$, where $\alpha > 0$ is sufficiently large. Consumer utility from purchasing a product of quality q for a price p is given by the utility function $U[\theta; q, p] = \theta q - p$. It is the net of the value obtained from purchasing (θq) and the disutility of having to pay for the product ($-p$). Each consumer in Period 1 either buys I or buys nothing and exits the market. Each consumer in Period 2 buys I or E or buys nothing and exits the market. No consumer buys more than one unit of a product or buys both products. Relaxing these assumptions complicates the analysis without adding any new qualitative insights.

The utility from buying I in Period 1 is

$$U_{I1} = \theta - p_{I1} \quad (1)$$

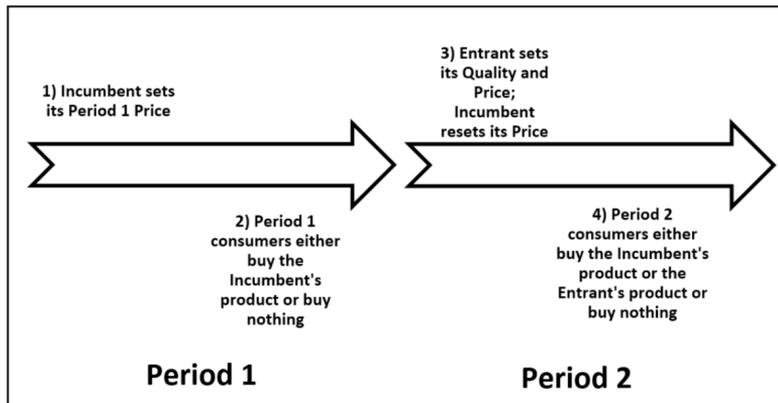
Similarly, the utility from buying I or buying E in Period 2 is as follows;

$$U_{I2} = \theta - p_{I2} \quad (2)$$

$$U_{E2} = \theta q - p_{E2} \quad (3)$$

The sequence of decision making is summarized as shown in Figure 1. This is a dynamic game of complete information. We solve it by backward induction using Game Theory.

Figure 1. Sequence of Decision-Making in Period 1 and Period 2



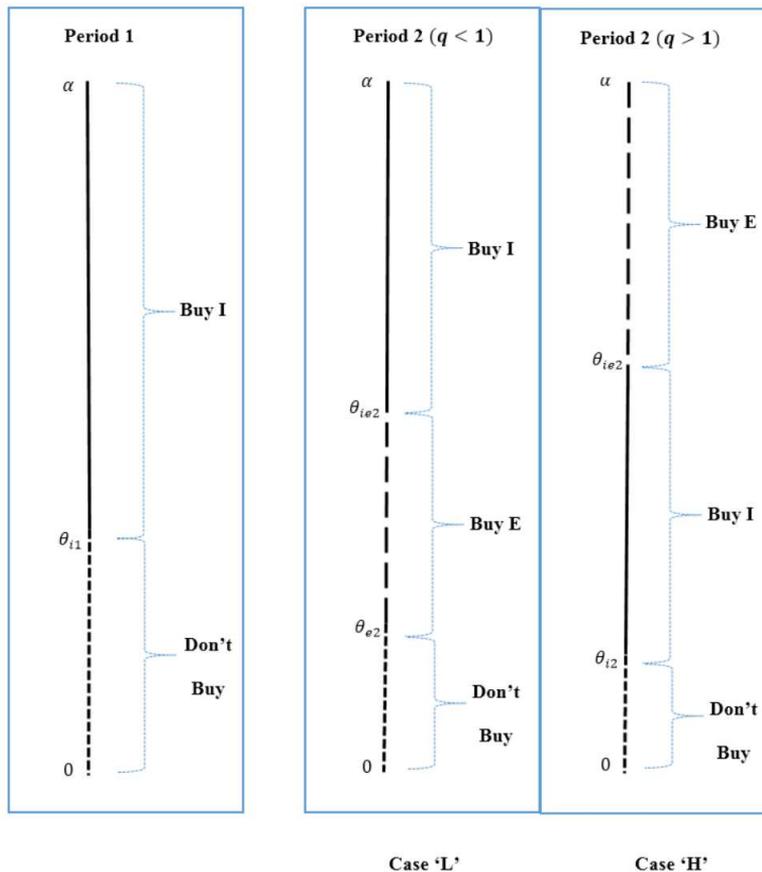
4. Analysis

The decision making takes place in four stages, referred to as Stage 1-4, as shown in Figure 1. We outline the backward induction solution procedure. Two cases can arise. The entrant may become the quality laggard or the quality leader, depending on whether it sets a relatively lower or higher quality than the incumbent. We analyse

each case, in turn and also determine the boundary conditions separating quality leadership and quality laggard ship as shown in Figure 2.

Figure 2 pictorially illustrates how the consumers' decision making differs in each case. As Figure 2 indicates, relatively high valuation consumers buy the higher-quality, higher-priced product, while relatively low valuation consumers buy the lower-quality, lower-priced product. The entrant's quality decision is driven by whether it more feasible to sell to high or low valuation consumers.

Figure 2. Consumers' Purchase Decisions



Case 1: The entrant is the quality laggard ($q < 1$)

We proceed by backward induction. To do this, we need to measure the firms' demand and profit functions. We first measure the consumer demand in Period 2. The basic idea is that a consumer buys a product if she gets a positive utility from her purchase and if her utility from this purchase is higher than her utility from purchasing the competing product. Consider the purchase decisions made in Period 2 when the entrant is the quality laggard. In Period 2, a consumer buys *E* if $U_{e2} > 0$ and $U_{e2} > U_{i2}$. Let θ_{e2} be the marginal valuation of consumers indifferent between buying *E* and not

buying anything. From (3), solving $U_{E2} = 0$ gives $\theta_{E2} = \frac{p_{E2}}{q}$. Let θ_{I2} be the marginal valuation of consumers indifferent between buying E and I . From (2) and (3), solving $U_{E2} = U_{I2}$ gives $\theta_{I2} = \frac{p_{I2} - p_{E2}}{1 - q}$. This means that in Period 2, consumers with marginal valuation $0 < \theta < \theta_{E2}$ do not buy anything, consumers with marginal valuation $\theta_{E2} < \theta < \theta_{I2}$ buy E , and the remaining consumers with marginal valuation $\theta_{I2} < \theta < \alpha$ buy I . The consumers' purchase behaviour is illustrated in Figure 2. This implies that in Period 2, the demand for E is $d_{E2} = \frac{\theta_{I2} - \theta_{E2}}{\alpha}$ and the demand for I is $d_{I2} = \frac{\alpha - \theta_{I2}}{\alpha}$. Next, we measure the consumer demand in Period 1. Solving $U_{I1} = 0$ gives $\theta_{I1} = p_{I1}$, implying that the demand for I in Period 1 is $d_{I1} = \frac{\alpha - p_{I1}}{\alpha}$. The demand for E in Period 1 is obviously zero.

There is incomplete market coverage since there are some low valuation consumers who do not make a purchase in both periods.

Given the demand functions, we can write the profit functions. The incumbent's profit is the sum of its profit from both periods, while the entrant's profit is its Period 2 profit. The incumbent's profit function is $\Pi_i = (p_{I1} - c_i)d_{I1} + (p_{I2} - c_i)d_{I2}$. The entrant's profit function is $\Pi_e = (p_{E2} - c_e)d_{E2}$. Substituting from above, we get the following profit functions, when the entrant is the quality laggard.

$$\Pi_e = (p_{E2} - \gamma q^2) \frac{\frac{p_{I1} - p_{E2}}{1 - q} - \frac{p_{E2}}{q}}{\alpha} \quad (4)$$

$$\Pi_i = (p_{I1} - \gamma) \frac{\alpha - p_{I1}}{\alpha} + (p_{I2} - \gamma) \frac{\alpha - \frac{p_{I2} - p_{E2}}{1 - q}}{\alpha} \quad (5)$$

Next we analyse the price competition. The incumbent and the entrant both set profit maximizing prices.

Case 2: The entrant is the quality leader ($q > 1$).

The analysis when the entrant is the quality leader is similar. Figure 2 illustrates the corresponding consumer purchase behaviour. The key difference is that relatively high valuation consumers buy E , since it is the quality leader. In this scenario, we get the following profit functions for the entrant and the incumbent.

$$\Pi_e = (p_{E2} - \gamma q^2) \frac{\alpha - \frac{p_{E2} - p_{I2}}{q - 1}}{\alpha} \quad (6)$$

$$\Pi_i = (p_{I1} - \gamma) \frac{\alpha - p_{I1}}{\alpha} + (p_{I2} - \gamma) \frac{\frac{p_{E2} - p_{I2}}{q - 1} - p_{I2}}{\alpha} \quad (7)$$

The derivations for both cases are available in the Appendix. We solve the firms' profit maximization problem by backward induction for both cases.

4.1 Quality

The equilibrium analysis yields the entrant's optimal product quality in Period 2, and how it compares with the incumbent's quality, as summarized in Result 1.

Result 1: Entrant's Quality compared to the incumbent's Quality:

| | <i>Market Conditions</i> | |
|---------------------------------------|---|---|
| | <i>Entrant is the Quality-Laggard</i> | <i>Entrant is the Quality-Leader</i> |
| | <i>Consumers' valuation is low</i> $\left(\frac{5\gamma}{4} < \alpha < 3\gamma\right)$ | <i>Consumers' valuation is high</i> $(3\gamma < \alpha)$ |
| <i>Entrant's Quality (q)</i> | $q^* = \frac{5}{2} - \sqrt{\frac{21\gamma - 4\alpha}{4\gamma}}$ | $q^* = \frac{\alpha}{3\gamma}$ |
| <i>Range of Entrant's Quality (q)</i> | $\frac{1}{2} < q^* < 1$ | $q^* > 1$ |

The entrant is the quality laggard ($q^* < 1$) if the maximum marginal valuation for quality is relatively low $\left(\frac{5\gamma}{4} < \alpha < 3\gamma\right)$. The entrant is the quality leader ($q^* > 1$) if the maximum marginal valuation for quality is relatively high ($\alpha > 3\gamma$).

The intuition behind Result 1 is as follows. If consumers' average marginal valuation for quality is relatively small, it means that there is relatively greater density of low valuation consumers in the market. In order to target these low valuation consumers, the entrant launches a lower quality product ($q^* < 1$) compared to the incumbent's quality. When the entrant is the Quality Laggard, $q^* = \frac{5}{2} - \sqrt{\frac{21\gamma - 4\alpha}{4\gamma}}$ and $\frac{5\gamma}{4} < \alpha < 3\gamma$. Since q^* is increasing in α , the minimum quality is set at $\alpha = \frac{5\gamma}{4}$. The entrant never sets $0 < q^* < \frac{1}{2}$ as it would make its demand zero. Thus we get $\frac{1}{2} < q^* < 1$.

4.2 Comparative Statics

The entrant's quality is influenced by a change in consumers' valuation for quality α . The entrant's quality is increasing in consumers' valuation $\left(\frac{\partial q^*}{\partial \alpha} > 0\right)$.

Next, we establish the range of the entrant's quality level in the model. To do this, we measure the minimum and maximum quality levels selected by the entrant when it is the quality laggard and when it is the quality leader. The analysis is summarized in Result 1. We have also captured this in Figure 3

Figure 3. Quality as a function of consumers' valuation (α), given $\gamma = 1$ and $\gamma = 0.8$.

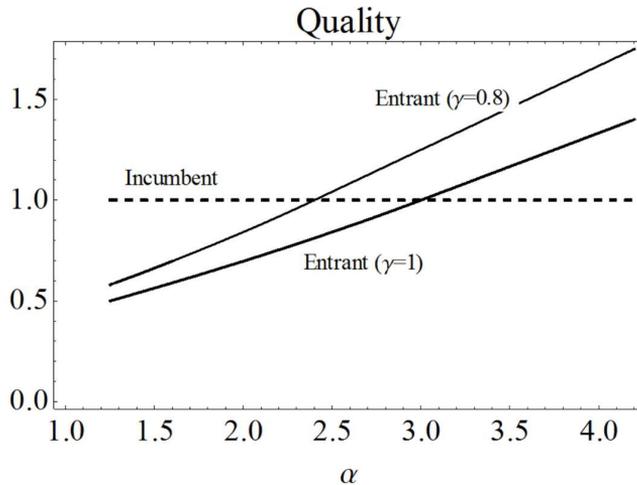


Figure 3 shows plots of the entrant's product quality as a function of α setting $\gamma = 1$ and $\gamma = 0.8$. If $\gamma = 1$, the entrant is the quality laggard ($q^* < 1$) if the maximum marginal valuation for quality is low ($\frac{\alpha}{4} < \alpha < 3$), but becomes the quality leader ($q^* > 1$) if α is high ($\alpha > 3$). The trend for $\gamma = 0.8$ is qualitatively similar. The plots also show that the entrant's quality is increasing in α . Further, for a fixed level of α , the entrant's quality is higher when $\gamma = 0.8$ as compared to when $\gamma = 1$. These plots are a visual illustration of Result 1.

An alternate way of thinking about Result 1 is in terms of the production efficiency γ for a fixed level of consumer valuation α . If the cost of production is relatively low ($\gamma < \frac{\alpha}{3}$), the entrant launches a higher quality product than the incumbent ($q^* > 1$). However, if the cost of production is relatively high ($\frac{\alpha}{3} < \gamma < \frac{4\alpha}{5}$), the entrant instead launches a lower quality product than the incumbent ($q^* < 1$). This makes intuitive sense. Next we review how a change in production efficiency (γ) influence the entrant's quality.

Suppose a technological advancement increases the production efficiency (i.e. γ decreases). If the production efficiency increases, the entrant raises its quality, since $\frac{\partial q^*}{\partial \gamma} < 0$. The entrant's quality is thus increasing in the production efficiency.

4.3 Pricing

4.3.1 Period 1

The incumbent is a monopoly in Period 1. It sets a monopoly price of $p_{11}^* = \frac{\alpha + \gamma}{2}$, corresponding to its unit product quality ($q_{11} = 1$). The price is increasing in consumers'

maximum valuation α and the production cost parameter γ . It is expectedly less than the maximum marginal valuation α .

Recall that the utility of period 1 consumers is $U_{11} = \theta - p_{11}$ and they buy I if and only if their utility is positive. This means that consumers having marginal valuation $\frac{\alpha+\gamma}{2} < \theta < \alpha$ buy I in Period 1, while consumers having marginal valuation $0 < \theta < \frac{\alpha+\gamma}{2}$ do not buy anything. This also means that the demand for I in Period 1 is $\frac{\alpha-\gamma}{2\alpha}$.

Next, we analyse the pricing decisions made by the entrant in Period 2. We also analyse the strategic influence of the entrant on the incumbent's pricing in Period 2. The pricing strategy is summarized in Result 2 and the derivation is available in the Appendix.

Result 2: Entrant's and Incumbent's Pricing Strategy

| | | |
|--|---|---|
| <i>PERIOD 1:</i> | | |
| <i>Incumbent's Price (p_{11}^*)</i> | $\frac{\alpha + \gamma}{2}$ | $\frac{\alpha + \gamma}{2}$ |
| <i>PERIOD 2:</i> | <i>Entrant is the Quality-Laggard</i> | <i>Entrant is the Quality-Leader</i> |
| | <i>Consumers' valuation is low</i> $\left(\frac{5\gamma}{4} < \alpha < 3\gamma\right)$ | <i>Consumers' valuation is high</i> $(\alpha > 3\gamma)$ |
| <i>Entrant's Price (p_{22}^*)</i> | $\frac{(14\gamma - \alpha)}{2\gamma} \sqrt{\gamma(21\gamma - 4\alpha)} - \frac{(64\gamma - 11\alpha)}{2}$ | $\frac{\alpha(2\alpha - 3\gamma)}{9\gamma}$ |
| <i>Incumbent's Price (p_{12}^*)</i> | $\frac{7}{2} \sqrt{\gamma(21\gamma - 4\alpha)} - \frac{(31\gamma - 4\alpha)}{2}$ | $\frac{\alpha}{3}$ |

We discuss the pricing in Period 2 when the entrant is the quality leader separately from when it is the quality laggard.

4.3.2 Pricing Strategy when the entrant is the Quality Leader ($q^* > 1$)

Let us first analyse the entrant's price when the entrant is the quality leader. When consumers' valuation is relatively high ($3\gamma < \alpha$), the entrant launches a product of quality $q^* = \frac{\alpha}{3\gamma}$, greater than the incumbent's quality (See Result 1) and the entrant sets its price as $p_{22}^* = \frac{\alpha(2\alpha-3\gamma)}{9\gamma}$ in this regime (See Result 2). The entrant's price is expectedly increasing in valuation α in this regime, $\frac{\partial p_{22}^*}{\partial \alpha} = \frac{4\alpha-3\gamma}{9\gamma} > 0$.

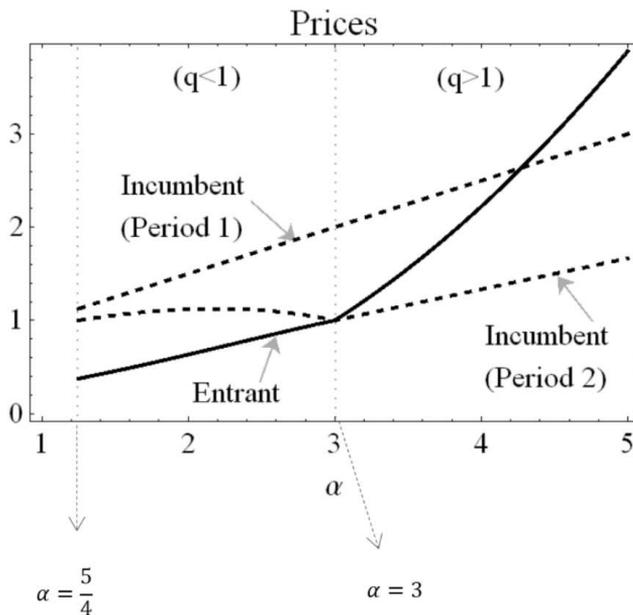
Next, let us analyse the incumbent's price when the entrant is the quality leader. The incumbent needs to strategically respond to the market entry in Period 2. Since the incumbent is unable to change its product quality, the only marketing instrument available to it is the price it charges. As summarized in Result 2, the

incumbent reduces its price from $p_{i1}^* = \frac{\alpha + \gamma}{2}$ in Period 1 to $p_{i2}^* = \frac{\alpha}{2}$ in Period 2, where $p_{i2}^* - p_{i1}^* = -\frac{\alpha + \gamma}{2} < 0$.

Considering comparative statics, it is easy to observe that the incumbent's price is increasing in α . Also we can see the limiting case that when $q^* = 1$, $p_{i2}^* = p_{e2}^* = \gamma$. This means that when $\alpha = 3\gamma$, then the entrant sets the same quality as the incumbent and in period two, both of them sell their products at the same price, which is intuitive. Here again, we verify that since the entrant is the quality leader, the entrant correspondingly sets a higher price than the incumbent, $p_{e2}^* - p_{i2}^* = \frac{2\alpha(\alpha - 3\gamma)}{9\gamma} > 0$.

Figure 4 numerically illustrates the pricing strategy for the special case $\gamma = 1$. As can be seen, the entrant is the quality leader ($q^* > 1$) for $\alpha > 3$. The dashed line shows the incumbent's price in Period 2 and Period 1. The solid line denotes the price profile of the entrant. The trends are consistent with Result 2.

Figure 4. Prices as a function of consumers' valuation (α), given $\gamma = 1$



4.3.3 Pricing Strategy when the entrant is the quality laggard ($\frac{1}{2} < q^* < 1$)

Consider the entrant's price when the entrant is the quality laggard. This happens when consumers' valuation is relatively low ($\frac{3\gamma}{4} < \alpha < 3\gamma$). In this regime, the entrant launches a product of quality $q^* = \frac{\alpha}{2} - \sqrt{\frac{21\gamma - 4\alpha}{4\gamma}}$, lower than the incumbent's quality (See Result 1) and the entrant sets its price as

$p_{22}^* = \frac{(14\gamma - \alpha)}{2\gamma} \sqrt{\gamma(21\gamma - 4\alpha)} - \frac{(64\gamma - 11\alpha)}{2}$ (See Result 2). The entrant's price is increasing in α in this regime, $\frac{\partial p_{22}^*}{\partial \alpha} > 0$ and the entrant's price varies between $\frac{5}{6}\gamma < p_{22}^* < \gamma$.

Next, let us analyse the incumbent's price response when the entrant is the quality laggard. From Result 2, the incumbent sets the following price $p_{12}^* = \frac{7}{2} \sqrt{\gamma(21\gamma - 4\alpha)} - \frac{(81\gamma - 4\alpha)}{2}$ in this regime. As expected, competition from the entrant forces the incumbent to reduce its price compared to Period 1, $p_{12}^* - p_{11}^* < 0$. Nevertheless, since the entrant is the quality laggard, the incumbent's price remains higher than the entrant's price, $p_{12}^* - p_{22}^* > 0$. The incumbent does forgo its monopoly power and reduce its Period 2 price compared to Period 1 ($p_{12}^* < p_{11}^*$), but it reduces it by a smaller amount compared to when it is the quality leader.

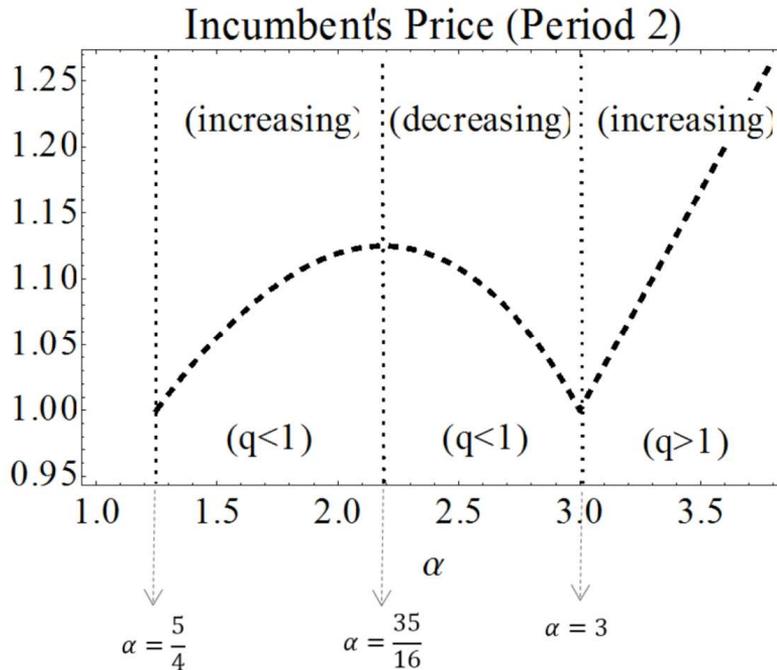
Considering comparative statics, the effect of a change in consumers' valuation α on the incumbent's pricing in Period 2 exhibits interesting behaviour. Naïve intuition suggests that an increase in α should always lead to an increase in the incumbent's price. However, as Result 3 and the subsequent analysis demonstrates, this need not be the case.

Result 3: The incumbent's price is non-monotonic in consumers' valuation (α), as follows.

| Entrant's Quality (q) | Range of Valuation (α) | Effect of α on Incumbent's Price Response |
|---------------------------|--|--|
| Laggard ($q < 1$) | Low ($\frac{5\gamma}{4} < \alpha < \frac{35\gamma}{16}$) | $\frac{\partial p_{12}^*}{\partial \alpha} > 0$ |
| | Medium ($\frac{35\gamma}{16} < \alpha < 3\gamma$) | $\frac{\partial p_{12}^*}{\partial \alpha} < 0$ |
| Leader ($q > 1$) | High ($3\gamma < \alpha$) | $\frac{\partial p_{12}^*}{\partial \alpha} > 0$ |

Result 3 shows that when the entrant is the quality laggard and consumers' valuation (α) for quality is in the medium range, the incumbent decreases its price despite an increase in α i.e. ($\frac{\partial p_{12}^*}{\partial \alpha} < 0$). This is counter-intuitive. An increase in α should normally lead to an increase in price. The reason for the reversal is that the price competition in the market becomes exceptionally strong. To understand this, recall from Result 1 that the entrant's quality is $q^* = \frac{5}{2} - \sqrt{\frac{21\gamma - 4\alpha}{4\gamma}}$ and as $\rightarrow 3\gamma$, we see that $q^* \rightarrow 1$. Since the incumbent's quality is 1, this means that the products becomes near substitutes leading to very high price competition between the incumbent and entrant. This price competition dominates the effect of increasing α , to the extent that it forces the incumbent to reduce its price ($\frac{\partial p_{12}^*}{\partial \alpha} < 0$). Result 3 is numerically illustrated in Figure 5.

Figure 5. The incumbent firm's price in period 2, as a function of consumers' maximum valuation (α), for $\gamma = 1$.



5. Discussion and Conclusion

This paper explores the market entry problem, addressing when should an entrant produce relatively higher (lower) quality than an incumbent. The model analysis shows that consistent with intuition, the entrant produces higher (lower) quality than the incumbent when the consumers' valuation for product quality is relatively large (small). More importantly, this paper also sheds light on the corresponding optimal pricing response by the incumbent, in the wake of competitive entry. As one might expect, the incumbent is forced to lower its price. However, how the incumbent reacts to an increase in consumers' valuation for quality is not obvious. It depends on whether the entrant is the quality leader or the quality laggard and potentially also on the extent of product differentiation between the firms. When the entrant is the quality leader, the incumbent's price is always increasing in consumers' valuation. But when the entrant is the quality laggard, the incumbent's price profile depends on the magnitude of product differentiation between the entrant and the incumbent as follows. For relatively high levels of product differentiation, the incumbent's price is increasing in consumers' valuation, whereas for relatively low levels of product differentiation, the incumbent's price is decreasing in consumers' valuation for quality.

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Appendix A

A.1 Case H: Entrant introduces a higher quality product ($q > 1$) than the incumbent ($q = 1$)

We solve the problem using the method of backward induction of game theory. Hence we start from Period 2.

Period 2: In period 2, consumers will buy low quality product, i.e., incumbent's product if, $U_{i2} > U_{e2}$ and $U_{i2} > 0$. Consumers will buy high quality product if, $U_{e2} > U_{i2}$ and $U_{e2} > 0$. Solving for the consumer utility function given by $U = \theta q - p$ we get,

$$\theta_{i2} = p_{i2} \quad (A1)$$

$$\theta_{ie2} = \frac{p_{e2} - p_{i2}}{q - 1} \quad (A2)$$

$$\theta_{e2} = \frac{p_{e2}}{q} \quad (A3)$$

The consumers will buy low quality product when $\theta_{i2} < \theta < \theta_{ie2}$ and consumers will buy high quality product when $\theta_{ie2} < \theta < \alpha$ ($\theta_i, \theta_e > 0$). The demand for incumbent d_{i2} and entrant d_{e2} are:

$$d_{i2} = \frac{\frac{p_{e2} - p_{i2}}{q - 1} - p_{i2}}{\alpha} \quad (A4)$$

$$d_{e2} = \frac{\alpha - \frac{p_{e2} - p_{i2}}{q - 1}}{\alpha} \quad (A5)$$

The margin for incumbent's and entrant's products m_{i2}, m_{e2} are:

$$m_{i2} = p_{i2} - \gamma \quad (A6)$$

$$m_{e2} = p_{e2} - \gamma q^2 \quad (A7)$$

The profit for incumbent and entrant Π_{i2}, Π_{e2} are:

$$\Pi_{i2} = m_{i2} d_{i2} \quad (A8)$$

$$\Pi_{e2} = m_{e2} d_{e2} \quad (A9)$$

Period 1: In this period, consumers will buy the incumbent's product if $U_{i1} > 0$. Solving for the consumer utility function given by $U = \theta q - p$,

$$\theta_{i1} = p_{i1} \quad (A10)$$

$$d_{i1} = \frac{\alpha - p_{i1}}{\alpha} \quad (A11)$$

$$m_{i1} = p_{i1} - \gamma \quad (A12)$$

$$\Pi_{i1} = m_{i1} d_{i1} \quad (A13)$$

Profit Maximization: The total profits are

$$\Pi_i = (p_{i1} - \gamma) \frac{(\alpha - p_{i1})}{\alpha} + (p_{i2} - \gamma) \frac{p_{e2} - p_{i2} - p_{i2}}{q - 1} \quad (A14)$$

$$\Pi_e = \Pi_{e2} = (p_{e2} - \gamma q^2) \frac{\alpha - \frac{p_{e2} - p_{i2}}{q - 1}}{\alpha} \quad (A15)$$

The profit maximization first-order conditions are $\frac{\partial \Pi_i}{\partial p_{i2}} = 0$, $\frac{\partial \Pi_e}{\partial p_{e2}} = 0$ and $\frac{\partial \Pi_e}{\partial q} = 0$.

Differentiating incumbent's total profit with respect to p_{i2} ,

$$\frac{\partial \Pi_i}{\partial p_{i2}} = \frac{p_{e2} + q(\gamma - 2p_{i2})}{(q - 1)\alpha} \quad (A16)$$

$$\frac{\partial^2 \Pi_i}{\partial p_{i2}^2} = -\frac{2q}{\alpha(q - 1)} < 0 \quad (A17)$$

Differentiating entrant's total profit with respect to p_{e2} ,

$$\frac{\partial \Pi_e}{\partial p_{e2}} = \frac{p_{i2} - 2p_{e2} - \alpha + q\alpha + q^2\gamma}{(q - 1)\alpha} \quad (A18)$$

$$\frac{\partial^2 \Pi_e}{\partial p_{e2}^2} = -\frac{2}{(q - 1)\alpha} < 0 \quad (A19)$$

Differentiating entrant's total profit with respect to q ,

$$\frac{\partial \Pi_e}{\partial q} = \frac{2p_{i2}q\gamma - p_{e2}p_{i2} - 2p_{e2}q\gamma + p_{e2}q^2\gamma - p_{i2}q^2\gamma - 2q\alpha\gamma + p_{e2}^2 + 4q^2\alpha\gamma - 2q^3\alpha\gamma}{(q - 1)^2\alpha} \quad (A20)$$

$$\frac{\partial^2 \Pi_e}{\partial q^2} = -\frac{2(p_{e2}^2 + (p_{i2} + (-1 + q)^2\alpha)\gamma - p_{e2}(p_{i2} + \gamma))}{(q - 1)^2\alpha} \quad (A21)$$

Solving $\frac{\partial \Pi_i}{\partial p_{i2}} = 0$, $\frac{\partial \Pi_e}{\partial p_{e2}} = 0$ and $\frac{\partial \Pi_e}{\partial q} = 0$, we get the feasible equilibrium

as $q^* = \frac{\alpha}{3\gamma}$, $p_{i2}^* = \frac{\alpha}{3}$ and $p_{e2}^* = \frac{\alpha(2\alpha - 3\gamma)}{9\gamma}$. Continuing with backward induction, we analyse

Period 1. Differentiating incumbent's profit in period-1 with respect to p_{i1}

$$\frac{\partial \Pi_i}{\partial p_{i1}} = \frac{\alpha + \gamma - 2p_{i1}}{\alpha} \quad (A22)$$

$$\frac{\partial^2 \Pi_i}{\partial p_{i1}^2} = -\frac{2}{\alpha} < 0 \quad (A23)$$

Setting $\frac{\partial \Pi_i}{\partial p_{i1}} = 0$, we get $p_{i1}^* = \frac{\alpha + \gamma}{2}$. So the equilibrium solution in this case is $p_{i1}^* = \frac{\alpha + \gamma}{2}$.

$p_{i2}^* = \frac{\alpha}{3}$, $p_{e2}^* = \frac{\alpha(2\alpha - 3\gamma)}{9\gamma}$, $q^* = \frac{\alpha}{3\gamma}$. But here, $q > 1$ which implies $\frac{\alpha}{3\gamma} > 1$ or $\alpha > 3\gamma$.

Also, we check that $\frac{\partial^2 \Pi_e}{\partial q^2} = -\frac{2(7\alpha - 3\gamma)\gamma}{3(\alpha - 3\gamma)} < 0$. Hence the solution obtained is a maximum:

$$p_{i1}^* = \frac{\alpha + \gamma}{2} \quad (A24)$$

$$p_{i2}^* = \frac{\alpha}{3} \quad (\text{A25})$$

$$p_{e2}^* = \frac{\alpha(2\alpha - 3\gamma)}{9\gamma} \quad (\text{A26})$$

$$q^* = \frac{\alpha}{3\gamma} \quad (\text{A27})$$

Thus the entrant prefers to be a quality leader in the market if the marginal valuation of quality by the customers is substantially higher than the marginal cost of producing that quality, namely

$$\alpha > 3\gamma \quad (\text{A28})$$

Intuitively speaking, people are ready to pay more for a better quality product and hence it is in best interests of the entrant to produce a higher quality product than the incumbent.

A.1.2 Case L: entrant introduces a lower quality product ($q < 1$) than the incumbent ($q = 1$)

Period 2: In period 2, consumers will buy low quality product, i.e., entrant's product if, $U_{e2} > U_{i2}$ and $U_{e2} > 0$. Consumers will buy high quality product if, $U_{i2} > U_{e2}$ and $U_{i2} > 0$. Solving for the consumer utility function given by $U = \theta q - p$ we get,

$$\theta_{i2} = p_{i2} \quad (\text{A29})$$

$$\theta_{ie2} = \frac{p_{i2} - p_{e2}}{1 - q} \quad (\text{A30})$$

$$\theta_{e2} = \frac{p_{e2}}{q} \quad (\text{A31})$$

The consumers will buy low quality product when $\theta_{e2} < \theta < \theta_{ie2}$ and consumers will buy high quality product when $\theta_{ie2} < \theta < \alpha$ ($\theta_1, \theta_h > 0$). The demand for incumbent's product d_{i2} and for the entrant's product d_{e2} are:

$$d_{e2} = \frac{\frac{p_{i2} - p_{e2}}{1 - q} - \frac{p_{e2}}{q}}{\alpha} \quad (\text{A32})$$

$$d_{i2} = \frac{\alpha - \frac{p_{i2} - p_{e2}}{1 - q}}{\alpha} \quad (\text{A33})$$

The margins for incumbent and entrant m_{i2}, m_{e2} are:

$$m_{i2} = p_{i2} - \gamma \quad (\text{A34})$$

$$m_{e2} = p_{e2} - \gamma q^2 \quad (\text{A35})$$

The profit for incumbent and entrant Π_{i2}, Π_{e2} are:

$$\Pi_{i2} = m_{i2} d_{i2} \quad (\text{A36})$$

$$\Pi_{e2} = m_{e2} d_{e2} \quad (\text{A37})$$

Period 1: Consumers will buy the incumbent's product if $U_{i1} > 0$. Solving the utility function, given by $U = \theta q - p$ we get,

$$\theta_{i1} = p_{i1} \quad (\text{A38})$$

$$d_{i1} = \frac{(\alpha - p_{i1})}{\alpha} \quad (\text{A39})$$

$$m_{i1} = p_{i1} - \gamma \quad (\text{A40})$$

$$\Pi_{i1} = m_{i1}d_{i1} \quad (A41)$$

Profit Maximization: The incumbent's total profit (Π_i) and the entrant's total profit (Π_e) are $\Pi_i = \Pi_{i1} + \Pi_{i2}$

$$\Pi_i = (p_{i1} - \gamma) \frac{\alpha - p_{i1}}{\alpha} + (p_{i2} - \gamma) \frac{\alpha - \frac{p_{i2} - p_{e2}}{1-q}}{\alpha} \quad (A42)$$

$$\Pi_e = \Pi_{e2} = (p_{e2} - \gamma q^2) \frac{\frac{p_{i2} - p_{e2}}{1-q} - \frac{p_{e2}}{q}}{\alpha} \quad (A43)$$

We proceed by backward induction. In Period 2, the entrant sets its price and quality, while the incumbent resets its period 1 price. Thus, the profit maximization first-order conditions are $\frac{\partial \Pi_i}{\partial p_{i2}} = 0$, $\frac{\partial \Pi_e}{\partial p_{e2}} = 0$ and $\frac{\partial \Pi_e}{\partial q} = 0$.

Differentiating incumbent's profit with respect to p_{i2} ,

$$\frac{\partial \Pi_i}{\partial p_{i2}} = \frac{p_{e2} - 2p_{i2} + \alpha - q\alpha + \gamma}{(1-q)\alpha} \quad (A44)$$

$$\frac{\partial^2 \Pi_i}{\partial p_{i2}^2} = -\frac{2}{(1-q)\alpha} < 0 \quad (A45)$$

Differentiating entrant's profit with respect to p_{e2} ,

$$\frac{\partial \Pi_e}{\partial p_{e2}} = \frac{q(p_{i2} + q\gamma) - 2p_{e2}}{(1-q)q\alpha} \quad (A46)$$

$$\frac{\partial^2 \Pi_e}{\partial p_{e2}^2} = -\frac{2}{(1-q)q\alpha} < 0 \quad (A47)$$

Differentiating entrant's profit with respect to q ,

$$\frac{\partial \Pi_e}{\partial q} = \frac{p_{e2}^2(2q-1) + p_{i2}(2-q)q^2\gamma - p_{e2}q^2(p_{i2} + \gamma)}{(1-q)^2q^2\alpha} \quad (A48)$$

$$\frac{\partial^2 \Pi_e}{\partial q^2} = -\frac{2[p_{e2}^2(1-2q+2q^2) + p_{i2}q^2\gamma - p_{e2}q^2(p_{i2} + \gamma)]}{(1-q)^3q^3\alpha} < 0 \quad (A49)$$

Solving $\frac{\partial \Pi_i}{\partial p_{i2}} = 0$, $\frac{\partial \Pi_e}{\partial p_{e2}} = 0$ and $\frac{\partial \Pi_e}{\partial q} = 0$, we get the feasible equilibrium

as $q^* = \frac{5\gamma - \sqrt{\gamma(21\gamma - 4\alpha)}}{2\gamma}$, $p_{i2}^* = \frac{7}{2}\sqrt{\gamma(21\gamma - 4\alpha)} + \frac{(4\alpha - 31\gamma)}{2}$ and

$$p_{e2}^* = \frac{(14\gamma - \alpha)}{2\gamma} \sqrt{\gamma(21\gamma - 4\alpha)} + \frac{(11\alpha - 64\gamma)}{2}$$

Differentiating incumbent's profit in period-1 with respect to p_{i1}

$$\frac{\partial \Pi_i}{\partial p_{i1}} = \frac{\alpha + \gamma - 2p_{i1}}{\alpha} \quad (A50)$$

$$\frac{\partial^2 \Pi_i}{\partial p_{i1}^2} = -\frac{2}{\alpha} < 0 \quad (A51)$$

Setting $\frac{\partial \Pi_i}{\partial p_{i1}} = 0$, we get $p_{i1}^* = \frac{\alpha + \gamma}{2}$. From A45, A47, A49 and A51 we see that second order derivatives are negative.

$$p_{i1}^* = \frac{\alpha + \gamma}{2} \quad (A52)$$

$$p_{12}^* = \frac{7}{2}\sqrt{\gamma(21\gamma - 4\alpha)} + \frac{(4\alpha - 31\gamma)}{2} \quad (A53)$$

$$p_{22}^* = \frac{(14\gamma - \alpha)}{2\gamma}\sqrt{\gamma(21\gamma - 4\alpha)} + \frac{(11\alpha - 64\gamma)}{2} \quad (A54)$$

$$q^* = \frac{5\gamma - \sqrt{\gamma(21\gamma - 4\alpha)}}{2\gamma} \quad (A55)$$

Applying the condition $q < 1$, we obtain $\alpha < 3\gamma$.

But we also need to ensure that the margin, demand and profit are also greater than zero at the equilibrium prices and qualities. Substituting back the equilibrium values into equation A47, we get $m_{11}^* = \frac{2(-4 + \sqrt{21-4\alpha})(\alpha-3\gamma)}{2 + \sqrt{21-4\alpha}}$ and solving for it to be greater than zero, we obtain a lower bound $\alpha = \frac{5\gamma}{4}$. Overall,

$$\frac{5\gamma}{4} < \alpha < 3\gamma \quad (A56)$$

Also, the second order derivatives are all negative at the equilibrium.

The equilibrium demands are

$$d_{11}^* = \frac{\alpha - \gamma}{2\alpha} \quad (A57)$$

If $\frac{1}{2} < q < 1$, then

$$d_{12}^* = \frac{4\gamma - \sqrt{\gamma(21\gamma - 4\alpha)}}{\alpha} \quad (A58)$$

$$d_{22}^* = \frac{5\gamma - \sqrt{\gamma(21\gamma - 4\alpha)}}{2\alpha} \quad (A59)$$

If $q > 1$, then

$$d_{12}^* = \frac{\gamma}{\alpha} \quad (A60)$$

$$d_{22}^* = \frac{1}{3} \quad (A61)$$

Profit of the incumbent and the entrant.

The equilibrium profits are as follows.

| | Incumbent's Profit (Π_1^*) |
|--|--|
| Consumers' valuation is low ($\frac{5\gamma}{4} < \alpha < 3\gamma$) | $\gamma\sqrt{\gamma(21\gamma - 4\alpha)}\left(\frac{61\gamma - 4\alpha}{2\alpha}\right) + \frac{\alpha^2 + 86\alpha\gamma - 557\gamma^2}{4\alpha}$ |
| Consumers' valuation is high ($\alpha > 3\gamma$) | $\frac{1}{12}\left(3\alpha - 2\gamma - \frac{9\gamma^2}{\alpha}\right)$ |
| | Entrant's Profit (Π_2^*) |
| Consumers' valuation is low ($\frac{5\gamma}{4} < \alpha < 3\gamma$) | $\sqrt{\gamma(21\gamma - 4\alpha)}\left(\frac{91\gamma - 9\alpha}{2\alpha}\right) - \frac{2\alpha^2 - 81\alpha\gamma + 417\gamma^2}{2\alpha}$ |
| Consumers' valuation is high ($\alpha > 3\gamma$) | $\frac{\alpha(\alpha - 3\gamma)}{27\gamma}$ |

A.1.3 Proofs of Results

Proof of Result 1: From equations A28, when $(q > 1)$, $\alpha > 3\gamma$. Similarly from equation A56, when $(q < 1)$ $\frac{5\gamma}{4} < \alpha < 3\gamma$. Also we had the statement: *The entrant's quality is increasing in consumers' valuation* ($\frac{\partial q^*}{\partial \alpha} > 0$). From A27, we see that when $\alpha > 3\gamma$, we have $q^* = \frac{\alpha}{3\gamma}$. So $\frac{\partial q^*}{\partial \alpha} = \frac{1}{3\gamma} > 0$. Similarly from A55, we can see that when $\frac{5\gamma}{4} < \alpha < 3\gamma$, we have $q^* = \frac{5\gamma - \sqrt{\gamma(21\gamma - 4\alpha)}}{2\gamma}$. Thus $\frac{\partial q^*}{\partial \alpha} = \frac{1}{\sqrt{\gamma(21\gamma - 4\alpha)}} > 0$.

Also we had stated that when the entrant is the Quality Laggard, its quality is lower bound as $\frac{1}{2} < q^* < 1$. Substituting the range $(\frac{5\gamma}{4} < \alpha < 3\gamma)$ in $q^* = \frac{5\gamma - \sqrt{\gamma(21\gamma - 4\alpha)}}{2\gamma}$, we get $\frac{1}{2} < q < 1$. Similarly, substituting the range $(\alpha > 3\gamma)$ in $q^* = \frac{\alpha}{3\gamma}$, we get $q > 1$. Hence proved. QED

Proof of Result 2: From equation A52-A54, we can see that when $(q < 1)$, $p_{i1}^* = \frac{\alpha + \gamma}{2}$, $p_{i2}^* = \frac{7}{2}\sqrt{\gamma(21\gamma - 4\alpha)} + \frac{(4\alpha - 31\gamma)}{2}$ and $p_{e2}^* = \frac{(14\gamma - \alpha)}{2\gamma}\sqrt{\gamma(21\gamma - 4\alpha)} + \frac{(11\alpha - 64\gamma)}{2}$. From equation A24-A26, we can see that when $(q > 1)$, $p_{i1}^* = \frac{\alpha + \gamma}{2}$, $p_{i2}^* = \frac{\alpha}{3}$ and $p_{e2}^* = \frac{\alpha(2\alpha - 3\gamma)}{9\gamma}$. QED

Proof of Result 3: From equation A53, we can see that when $(q < 1)$, $p_{i2}^* = \frac{7}{2}\sqrt{\gamma(21\gamma - 4\alpha)} + \frac{(4\alpha - 31\gamma)}{2}$. Hence differentiating with respect to α , we get $\frac{\partial p_{i2}^*}{\partial \alpha} = 2 - \frac{7\gamma}{\sqrt{\gamma(-4\alpha + 21\gamma)}}$. Solving for $\frac{\partial p_{i2}^*}{\partial \alpha} = 0$, we get $\alpha = \frac{35\gamma}{16}$. So we can see that when $(\frac{5\gamma}{4} < \alpha < \frac{35\gamma}{16})$, $\frac{\partial p_{i2}^*}{\partial \alpha} > 0$. At $\alpha = \frac{35\gamma}{16}$, $\frac{\partial p_{i2}^*}{\partial \alpha} = 0$. And for $\frac{35\gamma}{16} < \alpha < 3\gamma$, $\frac{\partial p_{i2}^*}{\partial \alpha} < 0$. Thus for $(q < 1)$, incumbent's price has a concave relation with consumers' valuation, i.e. as α increases, price increases till $\alpha = \frac{35\gamma}{16}$ and then decreases till $\alpha = 3\gamma$.

From equation A25, we can see that when $(q > 1)$, $p_{i2}^* = \frac{\alpha}{3}$. Differentiating with respect to α , we get $\frac{\partial p_{i2}^*}{\partial \alpha} = \frac{1}{3} > 0$. QED