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ABSTRACT

Credible Vertical Preemption

by Ralph Siebert*

In this study we investigate the incentives of incumbent firms to simultaneously introduce new products in different quality areas and their incentives to keep original products in the market. We show that new product introduction depends on the credibility of firms‘ innovation strategies and occurs only in certain quality areas. Preempting (deterring) the low quality firm from innovation is not a credible strategy for the high quality firm. It is shown that both firms introduce a new product of higher quality at a higher price in order to concentrate sales on high income consumers, whereby the high quality firm still offers the highest product quality. Moreover, the innovators always withdraw their original product from the market in order to reduce price competition and to avoid cannibalizing its own product demand. Finally, only two products are offered in the market.

ZUSAMMENFASSUNG

Glaubwürdiger vertikaler Verdrängungswettbewerb

In dieser Studie untersuchen wir die Anreize etablierter Unternehmen, neue Produkte mit unterschiedlicher Qualität in den Markt einzuführen. Weiterhin untersuchen wir die Anreize der Innovatoren, die alten Produkte vom Markt abzuziehen. Wir zeigen, daß die Einführung neuer Produkte von der Glaubwürdigkeit der Innovationsstrategien abhängt, und nur in bestimmten Marktsegmenten erfolgt. Das Unternehmen, welches Produkte mit hoher Qualität anbietet, kann das Unternehmen, welches Produkte mit niedriger Qualität anbietet, nicht glaubwürdig daran hindern, ein neues Produkt in den Markt einzuführen. Es wird gezeigt, daß beide Unternehmen ein neues Produkt mit höherer Qualität zum höheren Preis anbieten, wobei das Unternehmen mit hoher Qualität noch immer die höchste Produktqualität im Markt anbietet. Darüber hinaus wird gezeigt, daß die Innovatoren ihr altes Produkt aus dem Markt ziehen, um einen höheren Preiswettbewerb und Nachfrageverdrängungseffekte zu vermeiden. Folglich werden nur zwei Produkte im Markt angeboten.

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1 Introduction

Many industries are characterized by new product introduction of incumbent firms in an oligopolistic competition. Vertical differentiation is extensive in the electronics industry, especially in the personal computer market where technological progress motivates product innovation. When innovation occurs, we often observe that incumbents introduce new products of higher quality. For example, the development of the Pentium I processor displaced the personal computers equipped with 486-processors very quickly. The same process happened when the Pentium II processor was developed. Nowadays, almost every offered PC is equipped with the Pentium II processor. Furthermore, we often observe that original products are frequently withdrawn from the market when new products enter the market. The existing literature does not present a model of vertical product differentiation which explains why incumbent firms often introduce a new product of higher quality and why firms are better off to withdraw their original product from the market.

There are only few studies which analyze the decision of incumbent firms to keep or withdraw their original products after innovation occurred. All of them are using horizontal models in contrast to our setting which is a vertical product differentiation model. In horizontal models incumbents have the opportunity to proliferate the product space in order to prevent the rival (entrant) from introducing a new product, see also Prescott and Visscher (1977), Schmalensee (1978), and Eaton and Lipsey (1979). Judd (1985) emphasizes the relevance of commitment when product proliferation is used as an entry-deterrent strategy. He analyzes the decision of an incumbent firm to either keep the product close to the rival in the market or to withdraw it. The incumbent is faced with a trade-off in its decision: on the one hand, it would like to keep its product in the market which increases sales. On the other hand, withdrawing its product softens price competition which increases product prices. This dilemma is more intensive as the existing product space is more crowded since more of the firms' product prices are affected. Judd (1985) shows that the incumbent firm better withdraws its product close to the rival in order to soften price competition towards the rival's product. As a result, the firm earns higher profits despite a smaller variety of goods. He shows that the proliferation strategy by the incumbent firm may not be credible, once it is allowed to withdraw products from the market. Hence, for horizontal settings we are able to explain firms' incentives to withdraw their original products after innovation occurred.

It is still unclear how this argument applies to a vertical differentiation model where firms are characterized by earning asymmetric payoffs, since a higher quality gives higher profits.[1] In order to show what effects are important in a vertical

[1]Donnenfeld and Weber (1995) investigate the interplay between the strategies of single-product firms to accommodate, deter or blockade entry, and the magnitude of the entrants' set up costs. The authors show that incumbents can use limit qualities to deter entry and

differentiation model we introduce the following setting: Suppose that there are two firms offering one product with different quality. The quality space is characterized by numbers whereby a higher number refers to a higher product quality. Both firms offer their equilibrium qualities,[2] such that the low quality firm offers a product with quality, say *4/7*, and the high quality firm offers a product with quality *1*. The products are produced at the same marginal costs. Firms set prices in the product market, and no entry occurs. A technological progress occurs, which enables both firms to introduce a new product. The new product is allowed to be lower or higher in quality. A higher product quality requires a higher investment in R&D but also ensures higher profits. Furthermore, the firms have the choice to either keep or withdraw their original product from the market.

In order to illustrate the main mechanism, suppose that both firms introduce a new product of higher quality. In principle, there are two possible cases: *accommodation* or *preemption (deterrence)*. The high quality firm may *accommodate* the low quality firm's innovation by offering a new product, say with quality *5*, while withdrawing its original product in order to reduce price competition. The low quality firm's response is to offer a higher quality as well. Alternatively, the high quality firm might *preempt (deter)* the low quality firm from innovation by proliferating the product space. In this case, the high quality firm chooses a quality of its new product of, say *4*, and stays in the market with the original product. As a result, the low quality firm is *deterred* from innovating.

The high quality firm's decision on an *accommodation* or *deterrence* strategy is characterized by the following trade-off: (*i*) in the *accommodation strategy* the high quality firm introduces a higher product quality which softens price competition towards the rival's product and withdraws its original product yielding lower demand, (*ii*) in the *deterrence strategy* the high quality firm induces tougher price competition by offering a lower product quality but yields higher product demand by keeping the original product in the market. As we will show below, the high quality firm's *deterrence* strategy is not credible, since it can not commit to keep its original product in the market. The high quality firm is always better off by withdrawing its original product in the *deterrence* strategy in order to soften price competition. The low quality firm anticipates this commitment problem and introduces a new product with higher quality. Finally, the high quality firm's best response given that the low quality firm innovates, is to play

generate predictions about the correlations between the degree of product differentiation and the size of the entrants setup costs. Constantatos and Perrakis (1997) consider a multiproduct monopoly and show that disjoint intervals of fixed costs are existing, where it is sufficient for the monopolist to proliferate only parts of the market to deter entry. However, both studies analyze either single product firms entering an empty market or a monopolist offering more than one product. But our study considers a duopoly where incumbent firms introduce new products and may withdraw their former products.

[2]See also Choi and Shin (1992) and our model below concerning the equilibrium qualities.

the *accommodation* strategy while withdrawing its original product. The argument that the *deterrence strategy* is subject to a commitment problem, is similar to Judd (1985). Therefore, it is not restricted towards horizontal models, but also applies to vertical differentiation settings.

It is still unclear where the low quality firm locates its new product in the range between its original product with quality $4/7$ and the new product of the high quality firm with quality 5. There are several effects determining where the low quality firm locates its new product. It is well-known that product introduction in this range is subject to two countervailing effects, the *demand* and the *strategic effect*. The 'maximal product differentiation' principle by Shaked and Sutton (1982) suggests that moving product qualities apart in order to soften price competition (*strategic effect*) outweighs the increase in demand gained by moving qualities closer and capturing consumers from the high quality firm's product (*demand effect*). Applying the 'maximal product differentiation' principle, we may expect innovation to take place close to the original's product quality which softens price competition towards the rival's product. However, besides the principle of 'maximal product differentiation' the low quality firm also has to account for the impact on its original product when it stays in the market, i.e. the *cannibalization effect*. The *cannibalization effect* indicates that the innovator captures consumers from its original product demand. Thus, the low quality firm's decision to introducing a new product is determined by the following trade-off: (*i*) introducing a new product quality similar to the high quality firm's product increases its new product demand, reduces *cannibalization* towards its original product demand but increases price competition which also affects the original product, and (*ii*) introducing a new product similar to its original product quality softens price competition but decreases its new product demand and *cannibalizes* its original product demand. When the low quality firm withdraws the original product it looses consumers buying the original product but, in turn, softens price competition in the market. We will analyze these effects in the different innovation cases in more detail, below.

This study presents a first insight into the innovation incentives of incumbent firms in vertically differentiated markets. We find a way of solving the system since some cases (characterized by polynomials of high degrees) prevent us from solving the model by backward induction. Parceling out the total effects in several parts makes the analysis computationally tractable. In keeping with the analysis of Judd (1985) for horizontal models, this study shows that the credibility of strategies plays an important role in vertical product differentiation models, as well. The high quality firm's strategy to *deter* the competitor's innovation is not credible. We find that both innovators offer products of higher quality at higher prices whereby the high quality firm still offers the highest product quality when the production costs function for quality is symmetric. The innovators always withdraw their original product in order to avoid *cannibalizing* their own product demand and to reduce price competition.

The remainder of this study is organized as follows. In Section 2 we first describe the model of incumbent firms offering vertically differentiated products and analyze firms' incentives to introduce new products in different quality areas. We conclude in Section 3.

2 The Model

We consider an outset in which two firms ($i = 1, 2$) offer one product with quality $s_1^{0^*} = \frac{4}{7} s_2^{0^*}$ in the market. Thus, firm 1 is the low quality and firm 2 the high quality firm.[3] A technological progress improves the production technology which enables both firms to produce a new product. We model a three-stage duopoly game and investigate firms' incentives to introduce a new product and to withdraw their original product from the market.

In the first stage, both firms simultaneously decide if they introduce a new product and choose the quality of the new product $s_i^1 \in [0, \infty]$, for $i = 1, 2$. The new product quality is allowed to be lower or higher than the original product quality. We can distinguish between three quality areas which depend on where every innovator locates the new product: a low quality area, $s_i^1 < s_1^0$, an intermediate quality area, $s_1^0 < s_i^1 < s_2^0$, and a high quality area, $s_i^1 > s_2^0$. Firms have to invest in R&D when they produce higher quality but do not have to invest in R&D when they offer a new product with lower quality. The quality costs for the innovating firm, which already offers s_i^0, is described by the following costs function

$$F_i\left(s_i^1\right) = \begin{cases} 0 \text{ for } s_i^1 \leqq s_i^0 \\ > 0 \text{ for } s_i^1 > s_i^0, \end{cases}$$

where $F_i'\left(s_i^1\right) > 0$ and $F_i''\left(s_i^1\right) > 0$, with $s_i^1 > s_i^0$. Firms' quality choice is supposed to satisfy the 'best response' property. Firm i's choice on quality is described by

$$s_i^{1^*} = r_i^1\left(\left(s_1^0\right), \left(s_2^0\right), s_j^1\right) = \arg\max_{s_i^1} \left\{\pi_i^{(0),1} - F_i\left(s_i^1\right)\right\},$$

with i, $j = 1, 2$, and $i \neq j$.[4] We distinguish between two scenarios depending

[3] The chosen product qualities represent the equilibrium qualities in the model by Choi and Shin (1992) which is a modification of Shaked and Sutton (1982) whereby the version by Tirole (1992) is used. The results of their model are shown in Siebert (1999), Appendix 1. For further reference, this setting is also denoted as the outset. The superscript 0 denotes the product from the outset, whereby the subscript refers to the firms. For the purpose of using a convenient notation we will drop (from now on) the symbol '*' which indicates firms' equilibrium qualities from the outset.

[4] The variable $\pi_i^{k,l}$, for $k, l = 0, 1$ and $k \neq l$ refers to firm i's profits. The presence of both superscripts k and l indicates that firm i offers both products in the market. Whereas one superscript (e.g. π_i^k) indicates that firm i offers only one product in the market. Moreover, $\pi_i^{(k),l}$ for $k, l = 0, 1$ and $k \neq l$ indicates that firm i has the opportunity to keep or withdraw the corresponding product with index k from the market.

on which of the innovators offers the highest product quality: the high quality firm offers the highest product quality, and the low quality firm offers the highest product quality.[5]

In the second stage, the firms decide whether to keep or withdraw the original product from the market given their quality decision from the first stage. In terms of the number of products the following cases may occur: both innovators keep the first product in the market and four products are offered in the market, one of the innovators withdraws the first product and three products are offered, and both innovators withdraw their original product and two products remain in the market.

Tables 2.1 and 2.2 show all the different innovation cases. In order to get a better understanding of the different cases, we use the following notation: the number refers to the firm which offers the product. The products are ranked in increasing quality order, that is, a number at the bottom indicates the lowest product quality and a number at the top the highest. Bold numbers indicate the new product of each firm and a number in brackets indicates the option to either stay or withdraw the former product from the market. Note, the outcome for the case when no innovation occurs is given by the outset.

The High Quality Firm offers the Highest Product Quality

a	**b**	**c**
2	**2**	**2**
(2)	(2)	**1**
(1)	**1**	(2)
1	(1)	(1)

Table 2.1: Innovation cases when the high quality firm offers the highest product quality

[5] A scenario in which both firms introduce a product lower in quality than the former highest industry quality s_2^0 does not exist because of the following argument: Siebert (1999) shows that a single innovator (firm i) offers a new product only, when it is of superior quality, $s_i^1 > s_2^0 = \frac{7}{4}s_1^0$ for $i = 1, 2$. Thus, any set of qualities for the single innovator case is given by $\left\{\left(s_1^0\right), \left(s_2^0\right), s_i^1\right\}$, with $s_i^1 > s_2^0$. As a result, there is no set of qualities with a new product lower in quality than the former highest industry quality $s_i^1 < s_2^0$ existing in the single innovator case. Because firms act according to the 'best response' in the simultaneous innovation case, but a single innovator only introduces a new product higher in quality than s_2^0, it follows, that a case in which both firms offer a new product lower in quality than s_2^0 does not exist.

The Low Quality Firm offers the Highest Product Quality

d	e	f
1	**1**	**1**
(2)	(2)	**2**
(1)	**2**	(2)
2	(1)	(1)

Table 2.2: Innovation cases when the low quality firm offers the highest product quality

In the third stage, firms maximize profits by simultaneously choosing prices in the product market having observed the product qualities and the number of products in the market. When the innovator keeps its original product in the market it is allowed to internalize price competition among its own products and takes into account that a price change of one of its products has an impact on its other product. No entry is assumed to occur. Production costs do not depend on quality and are set to 0.

Consumers' preferences are described by $U = \theta s - p$ if they buy a good and zero otherwise. Each consumer has the same ranking of qualities and prefers higher quality for a given price (p). Consumers differ in their income. Their income parameter θ is equally distributed over the interval $[0, 1]$. The assumption on the income parameter implies that the market is not covered; hence, some consumers do not buy any one of these products. Every consumer is allowed to buy at most one of the products.

We look for pure strategies and solve the model by investigating each innovation case separately. We begin with analyzing the innovation scenario from Table 2.1 when the high quality firm offers the highest product quality.

2.1 The High Quality Firm Offers the Highest Product Quality

When the high quality firm offers a new product in the high quality area three cases (a, b, and c) may occur depending on the low quality firm's action, see also Table 2.1. The low quality firm may offer a new product in the low quality area (case a), in the intermediate quality area (case b), or in the high quality area (case c). In all cases firms decide whether to keep or withdraw their original product from the market. We begin by analyzing case a.

Low Quality Innovation by the Low Quality Firm (Case a)

We solve this innovation case by applying backward induction. First, we derive prices, demand, and profits in the product market for each of the possible four

subgames: when both firms keep their original product in the market, when only the low quality firm withdraws, when only the high quality firm withdraws, and when both firms withdraw their original product from the market. We then analyze the innovators' decision to keep or withdraw their original product from the market. Finally, we investigate firms' incentives to introduce a new product in the quality areas under consideration.

Product Market Competition - Stage 3: When both firms keep their first product in the market the following sequence of product qualities $s_1^1 < s_1^0 < s_2^0 < s_2^1$ is offered in the market. Four indifferent consumers are in the market. One of them is indifferent between buying the high quality firm's new product with quality s_2^1 and buying its original product with quality s_2^0. The income parameter of this consumer is given by $\theta_4 = \frac{\left(p_2^1 - p_2^0\right)}{\left(s_2^1 - s_2^0\right)}$. The consumer who is indifferent between buying the high quality firm's original product with quality s_2^0 and the low quality firm's original product with quality s_1^0 is described by the income parameter $\theta_3 = \frac{\left(p_2^0 - p_1^0\right)}{\left(s_2^0 - s_1^0\right)}$. The consumer being indifferent between buying the original and the new product from the low quality firm is given by $\theta_2 = \frac{\left(p_1^0 - p_1^1\right)}{\left(s_1^0 - s_1^1\right)}$, whereas the income parameter $\theta_1 = \frac{p_1^1}{s_1^1}$ represents the consumer who is indifferent between buying the product with lowest quality and not buying at all. For the demand functions, we get

$$D_2^1\left(p_2^0, p_2^1, s_2^0, s_2^1\right) = \int_{\theta_4}^{\theta=1} f\left(\theta\right) d\theta = 1 - \frac{\left(p_2^1 - p_2^0\right)}{\left(s_2^1 - s_2^0\right)}, \tag{1}$$

$$D_2^0\left(p_1^0, p_2^0, p_2^1, s_1^0, s_2^0, s_2^1\right) = \int_{\theta_3}^{\theta_4} f\left(\theta\right) d\theta = \frac{\left(p_2^1 - p_2^0\right)}{\left(s_2^1 - s_2^0\right)} - \frac{\left(p_2^0 - p_1^0\right)}{\left(s_2^0 - s_1^0\right)}, \tag{2}$$

$$D_1^0\left(p_1^1, p_1^0, p_2^0, s_1^1, s_1^0, s_2^0\right) = \int_{\theta_2}^{\theta_3} f\left(\theta\right) d\theta = \frac{\left(p_2^0 - p_1^0\right)}{\left(s_2^0 - s_1^0\right)} - \frac{\left(p_1^0 - p_1^1\right)}{\left(s_1^0 - s_1^1\right)}, \tag{3}$$

and

$$D_1^1\left(p_1^1, p_1^0, s_1^1, s_1^0\right) = \int_{\theta_1}^{\theta_2} f\left(\theta\right) d\theta = \frac{\left(p_1^0 - p_1^1\right)}{\left(s_1^0 - s_1^1\right)} - \frac{p_1^1}{s_1^1}. \tag{4}$$

Firms' objective functions for the product market are

$$\pi_1^{1,0}(p_1^1, D_1^1, p_1^0, D_1^0) = p_1^1 D_1^1\left(\cdot\right) + p_1^0 D_1^0\left(\cdot\right), \text{ and}$$

$$\pi_2^{0,1}\left(p_2^0, D_2^0, p_2^1, D_2^1\right) = p_2^0 D_2^0\left(\cdot\right) + p_2^1 D_2^1\left(\cdot\right).$$

Each firm maximizes its profit function with respect to its own product price. The first order condition for the low quality firm, with respect to the price for the low quality product, is

$$\frac{\partial \pi_1^{1,0}(p_1^1, D_1^1, p_1^0, D_1^0)}{\partial p_1^1} \equiv 0 \Longrightarrow p_1^1\left(p_1^0\right) = \frac{p_1^0 s_1^1}{s_1^0},$$

and with respect to its original product price,

$$\frac{\partial \pi_1^{1,0}(p_1^1\left(p_1^0\right), D_1^1, p_1^0, D_1^0)}{\partial p_1^0} \equiv 0 \Longrightarrow p_1^0\left(p_2^0\right) = \frac{p_2^0 s_1^0}{2s_2^0}.$$

Note that the innovator is allowed to internalize the price effect of its own product prices. The first order condition for the high quality firm with respect to its new product price, is as follows

$$\frac{\partial \pi_2^{0,1}(p_2^0, D_2^0, p_2^1, D_2^1)}{\partial p_2^1} \equiv 0 \Longrightarrow p_2^1\left(p_2^0\right) = \frac{2p_2^0 - s_2^0 + s_2^1}{2},$$

and with respect to its original product price, taking the price effect of its product prices into account, is given by

$$\frac{\partial \pi_2^{0,1}(p_2^0, D_2^0, p_2^1\left(p_2^0\right), D_2^1)}{\partial p_2^0} \equiv 0 \Longrightarrow p_2^0\left(p_1^0\right) = \frac{p_1^0 - s_1^0 + s_2^0}{2s_2^0}.$$

The reaction functions are strictly monotone and have a unique Nash equilibrium. Solving the first order conditions yields the corresponding equilibrium prices

$$p_1^1(s_1^1, s_1^0, s_2^0) = \frac{s_1^1\left(s_1^0 - s_2^0\right)}{s_1^0 - 4s_2^0},\ p_1^0(s_1^0, s_2^0) = \frac{s_1^0\left(s_1^0 - s_2^0\right)}{s_1^0 - 4s_2^0},$$

$$p_2^0(s_1^0, s_2^0) = \frac{2s_2^0\left(s_1^0 - s_2^0\right)}{s_1^0 - 4s_2^0},\ p_2^1(s_1^0, s_2^0, s_2^1) = \frac{1}{2}\left\{s_2^1 - s_2^0 + \frac{4s_2^0\left(s_1^0 - s_2^0\right)}{s_1^0 - 4s_2^0}\right\}.$$

Substituting these into equations (1) to (4) gives us the equivalent demand

$$D_1^1\left(\cdot\right) = 0,\ D_1^0\left(s_1^0, s_2^0\right) = \frac{s_2^0}{4s_2^0 - s_1^0},\ D_2^0\left(s_1^0, s_2^0\right) = \frac{s_1^0}{8s_2^0 - 2s_1^0},\ D_2^1\left(\cdot\right) = \frac{1}{2}.$$

Firms' profits in the product market are

$$\pi_1^1\left(\cdot\right) = 0,\ \pi_1^0\left(s_1^0, s_2^0\right) = \frac{s_1^0 s_2^0\left(s_2^0 - s_1^0\right)}{\left(4s_2^0 - s_1^0\right)^2},\ \pi_2^0\left(s_1^0, s_2^0\right) = \frac{s_1^0 s_2^0\left(s_2^0 - s_1^0\right)}{\left(s_1^0 - 4s_2^0\right)^2}, \tag{5}$$

$$\text{and } \pi_2^1\left(s_1^0, s_2^0, s_2^1\right) = \frac{1}{4}\left\{\frac{4s_2^0\left(s_1^0 - s_2^0\right)}{s_1^0 - 4s_2^0} + s_2^1 - s_2^0\right\}$$

When only the low quality firm withdraws the original product from the market the sequence of qualities is given by $s_1^1\,(< s_1^0) < s_2^0 < s_2^1$.[6] The results are the same as for case a in Siebert (1999), setting $s_1^1 = s_1^0$.

When only the high quality firm withdraws the original product from the market the quality order is given by $s_1^1 < s_1^0\,(< s_2^0) < s_2^1$. The results are shown in case f in Siebert (1999), adjusted for $s_2^1 = s_2^0$.

When both innovators withdraw the original product from the market the following sequence of qualities is offered in the market $s_1^1\,(< s_1^0)\,(< s_2^0) < s_2^1$. The results are similar to the outset shown in Siebert (1999), setting $s_1^1 = s_1^0$ and $s_2^1 = s_2^0$.

As we see, firms' profits in the product market depend on the product qualities and the number of products offered in the market.

We now turn to investigate the innovators' decision to keep or withdraw the original product from the market.

Number of Products - Stage 2: In this stage the innovators decide how many products they offer in the market. Each firm has the choice to keep or withdraw the original product from the market taking the rival's choice into account. The innovator keeps the original product in the market, whenever

$$\pi_i^{0,1}\left(s_i^0, s_i^1, \left(s_j^0\right) s_j^1\right) - \pi_i^1\left(s_i^1, \left(s_j^0\right) s_j^1\right) > 0. \tag{6}$$

Polynomials of high degrees prevent us from explicitly solving the innovators' first order conditions of their profit functions with respect to their qualities. Therefore, we investigate firms' marginal profits in stage 3 with respect to their original product quality in order to analyze the innovators' decision on the number of products.

We begin by analyzing the low quality firm's decision on the number of products.

When the high quality firm keeps the first product in the market the low quality firm's best action is to keep the original product in the market, since

$$\frac{\partial \pi_1^{1,0}\left(s_1^1, s_1^0, s_2^0, s_2^1\right)}{\partial s_1^0} = \frac{\partial\left[\frac{s_1^0 s_2^0\left(s_2^0 - s_1^0\right)}{\left(s_1^0 - 4s_2^0\right)^2}\right]}{\partial s_1^0} = \frac{\left(7s_1^0 - 4s_2^0\right) s_2^{0^2}}{\left(s_1^0 - 4s_2^0\right)^3} \Longrightarrow s_1^0 = \frac{4}{7} s_2^0$$

applies.

[6] The product quality in brackets indicates that the product is withdrawn from the market.

When the high quality firm withdraws the first product, the same argument as in Siebert (1999), case f applies. The low quality firm internalizes price competition towards its own product prices by setting the price of the new product relatively high in order to capture more consumers for buying the original product which is of higher quality and earns higher profits. It follows that the low quality firm is better off to keep the original product in the market. Hence, the low quality firm has a dominant strategy to keep the original product in the market after introducing a new product in the low quality area.

The high quality firm's choice to either keep or withdraw the original product taking into account that the low quality firm always keeps the first product in the market is similar to case a in Siebert (1999).[7] The high quality firm's best choice is to withdraw the original product in order to avoid *cannibalizing* its new product demand and softening price competition in the market, see equation (9).

As a result, the low quality firm keeps the original product in the market when it introduces a new product in the low quality area, whereas the high quality firm withdraws the original product when it introduces a new product in the high quality area.

Quality Choice - Stage 1: In this stage the innovators' incentive to introduce a new product is analyzed, taking into account that the high quality firm withdraws the original product, whereas the low quality firm keeps the original product in the market.

The innovator's (firm i's) objective is to choose a product quality which maximizes first-stage profits, given by

$$\Pi_i^{(0),1}\left(\cdot, s_i^1, s_j^1\right) = \pi_i^{(0),1}\left(\cdot, s_i^1, s_j^1\right) - F_i\left(s_i^1\right). \tag{7}$$

Taking the low quality firm's first order condition of equation (7) with respect to its new product quality s_1^1 shows that the low quality firm will not introduce a new product in the low quality area in order to avoid *cannibalizing* the demand of its first product, see Siebert (1999), equation (31).

The high quality firm's profits increase by introducing a new product in the high quality area, see Siebert (1999), equation (34), setting $s_2^1 = s_2^0$. Whether the high quality firm has an incentive to introduce a new product is a comparison of the high quality firm's first-stage profits when it introduces a new product with the profits when no innovation occurs. The high quality firm's objective function is given by

$$\pi_i^1\left(\cdot, s_i^1\right) - F_i\left(s_i^1\right) - \Omega_i^0\left(\cdot, s_i^0\right) \tag{8}$$

[7] Note, the low quality firm always sets the price for the product with lowest quality sufficiently high, such that no consumer will buy the product, see equation (5) setting $s_1^0 = s_1^1$, and vice versa. Finally, this case is analogous to case a where three products are offered in the market.

where $\Omega_i^0(\cdot, s_i^0)$ indicates the innovator's profits (stage 1) when no innovation occurs, for $i = 2$. Equation (8) shows that the high quality firm may introduce a new product in the high quality area depending on the R&D costs for quality.

Overall, we can summarize case *a* as follows: The high quality firm may introduce a new product in the high quality area depending on the R&D costs and withdraws the original product from the market whereas the low quality firm does not introduce a new product.

We turn to investigate case *b*.

Intermediate Quality Innovation by the Low Quality Firm (Case b)

Product Market Competition - Stage 3: The results for the product market are determined by the innovators' decision to keep or withdraw the original product. For prices, demand and profits see also the previous case *a*, equation (4), in Appendix 4, and Appendix 1, see Siebert (1999), adjusted for the corresponding product qualities.

Before we turn to analyze the innovators' decision on the number of products (stage 2), and their quality choices (stage 1), we provide insight to the high quality firm's choices in stage 2 and stage 1, in order to emphasize the credibility of firms' innovation strategies and also to stress the link between horizontal and vertical product differentiation models.

The high quality firm may keep the original product in the market, in order to *deter* the low quality firm's innovation:

When the high quality firm keeps the original product in the market the low quality firm does not introduce a new product in the intermediate area.[8]

However, the high quality firm may also withdraw the original product from the market, in order to *accommodate* the low quality firm's innovation:

When the high quality firm withdraws the original product from the market after innovating, the low quality firm introduces a new product in the intermediate quality area and withdraws, as well.[9]

The high quality firm's decision to *deter* or *accommodate* the low quality firm's innovation (stage 2) is a comparison of profits in both cases as shown in equation (6). The high quality firm's decision on product quality (stage 1) is based on its objective function (7). In accordance to subgame perfection, we begin by analyzing stage 2.

Number of Products - Stage 2: The decision to keep or withdraw the original product from the market (stage 2) is a comparison of profits under both scenarios,

[8]Equation (5), with $s_1^1 = s_1^0$ shows that the low quality firm's profits (stage 3) are identical to the outset, as shown in Siebert (1999), Appendix 1, equation (32). It turns out that s_1^0 represents the low quality firm's optimal product quality for this scenario. Therefore, the low quality firm has no incentive to introduce a new product in the intermediate quality area.

[9]Note, that we have a similar situation to the outset, where product qualities are adjusted to $s_1^1 = s_1^0$, and $s_2^1 = s_2^0$.

as shown in equation (6). In contrast to the previous innovation case a, the low quality firm has a dominant strategy to withdraw the original product from the market.[10]

Given the low quality firm withdraws the original product, the high quality firm withdraws as well, in order to lower price competition and to avoid cannibalizing its new product demand, see Siebert (1999), equation (9).

Consequently, both firms withdraw their original product in this innovation case.

Quality Choice - Stage 1: In this stage, the innovation incentives are analyzed, taking into account that both firms withdraw their original product from the market.[11] The innovator's (firm i's) objective is to choose a product quality which maximizes profits, according to

$$\Pi_i^1\left(s_i^1, s_j^1\right) = \pi_i^1\left(s_i^1, s_j^1\right) - F_i\left(s_i^1\right).$$

Taking the derivative with respect to its new product quality s_i^1 shows that the innovator's marginal profits (stage 3) are positive (see Siebert [1999], Appendix 1, equation (**??**) and (34), setting $s_1^1 = s_1^0$ and $s_2^1 = s_2^0$). Therefore, firms' incentives to introduce a new product in the market depends on the R&D costs for quality, as shown in equation (33).

We could show that firms' incentives to introduce a new product depend on the R&D costs. Moreover, once firms introduce a new product they both withdraw their original product from the market. Therefore, the high quality firm's choice to *deter* the low quality firm's innovation is not credible.

We can summarize case b, with the following proposition.

Proposition 1 *The high quality firm's innovation strategy to deter the low quality firm's innovation is not credible. The high quality firm accommodates the low quality firm's innovation. When innovation occurs, both firms withdraw their original product from the market.*

In order to provide insight for this result, we compare the high quality firm's choice to *deter* or *accommodate* innovation, which are determined by the following effects[12]

[10] When the high quality firm withdraws the original product the outcome is similar to case e in Siebert (1999), see equation (41). Therefore, equation (23) in Siebert (1999), adjusted for $s_2^1 = s_2^0$ shows that the low quality firm withdraws the original product.

When the high quality firm keeps the original product in the market, (see equation (5) with $s_1^0 = s_1^1$, and vice versa) the low quality firm withdraws the original product.

[11] Note, that we have a similar situation to the outset, where product qualities are adjusted to $s_1^1 = s_1^0$, and $s_2^1 = s_2^0$.

[12] Any variable indicated by a bar (like $\overline{s}_2^1$) refers to the deterrence case, whereas all other variables refer to the accommodation case.

$$\underbrace{\frac{\partial \pi_2^1}{\partial s_2^1} + \frac{\partial \pi_2^1}{\partial s_1^1}}_{Accommodation} \gtrless \underbrace{\frac{\partial \overline{\pi}_2^{0,1}}{\partial \overline{s}_2^1}}_{Deterrence}$$

$$\overbrace{\underbrace{\frac{\partial \pi_2^1}{\partial D_2^1}\frac{\partial D_2^1}{\partial p_1^1}\frac{\partial p_1^1}{\partial s_2^1}}_{Own\ strategic\ effect}}^{+} \gtrless \overbrace{\underbrace{\frac{\partial \overline{\pi}_2^{0,1}}{\partial \overline{D}_2^0}\frac{\partial \overline{D}_2^0}{\partial \overline{s}_2^1} + \frac{\partial \overline{\pi}_2^{0,1}}{\partial \overline{D}_2^1}\frac{\partial \overline{D}_2^1}{\partial \overline{s}_2^1}}_{Demand\ effect\ in\ deterrence\ case} - \underbrace{\frac{\partial \pi_2^1}{\partial D_2^1}\frac{\partial D_2^1}{\partial s_2^1}}_{Demand\ effect} - \left[\underbrace{\overbrace{\frac{\partial \pi_2^1}{\partial D_2^1}\frac{\partial D_2^1}{\partial p_1^1}\frac{\partial p_1^1}{\partial s_1^1} + \frac{\partial \pi_2^1}{\partial D_2^1}\frac{\partial D_2^1}{\partial s_1^1}}^{-}}_{Rival's\ strategic\ effect\ in\ accom.\ case}\right]}^{+} \tag{9}$$

In the *accommodation* case, the high quality firm produces a higher quality than in the *deterrence* case.[13] The high quality firm benefits by producing a higher product quality, because price competition towards the low quality product is softened, see *own strategic effect* in equation (9). On the other hand, the high quality firm looses part of its profits (stage 3) in the *accommodation* case because the low quality firm's new product quality increases price competition and takes over some of the product demand from the high quality firm, indicated by the *rival's strategic effect* in equation (9).

In the *deterrence* case, the high quality firm offers a lower product quality and benefits less by softening price competition. However, it benefits by a higher *demand effect* and avoiding a negative *rival's strategic effect* caused by the low quality firm's product innovation in the *accommodation* case, see equation (9).

The high quality firm's decision to *deter* or *accommodate* the low quality firm's innovation seems to depend on the extent of the low quality firm's potential innovation in the *accommodation* case: the high quality firm may prefer to *accommodate* innovation when it benefits more from softening price competition by offering a higher product quality than it suffers from an increase in price competition and a lower demand effect determined by the low quality firm's new product quality. On the other hand, the high quality firm may prefer to *deter* the low quality firm's innovation, when its new product quality is relatively high and intensifies price competition. The high quality firm may keep the first product in the market, offering a product with lower quality. As a result, the low quality

[13] From Siebert (1999), Appendix 1 with $s_1^1 = s_1^0$ and $s_2^1 = s_2^0$, and Siebert (1999), Appendix 2, equation (38), with $s_2^1 = s_2^0$ and vice versa, we know that marginal profits (stage 3) in the *accommodation* case are higher than in the *deterrence* case because $\frac{\partial \pi_2^1(s_1^1, s_2^1)}{\partial s_2^1} - \frac{\partial \pi_2^{0,1}(s_1^0, s_2^0, s_2^1)}{\partial s_2^1} = -\frac{{s_2^1}^2(s_1^1 + 20 s_2^1)}{4(s_1^1 - 4 s_2^1)^3} \geq 0$ applies.

firm would be *deterred* from innovation which prevents fierce price competition, see equation (9).

However, it is still left to show if the high quality firm's chosen *deterrence* strategy would be credible.

Firm 1 \ **Firm 2**	Accommodation[14]	Deterrence
Accommodation	$2, \frac{5}{2} + x$	$\frac{1}{2}, \frac{3}{4}$
Deterrence	$\frac{7}{4}, 4$	$1, 3$

Table 2.3: Firms' profits in the *accommodation* and *deterrence* case

As we see in Table 2.3,[15] once the low quality firm chose to play the *deterrence* strategy the high quality firm is better off to withdraw the first product from the market in order to lower price competition and to avoid cannibalizing its own demand, see equation (9). The best reply for the low quality firm is to increase its original product quality, see Siebert (1999), Appendix 1, equation (33). It follows that the high quality firm always prefers to withdraw the original product from the market.

As we have shown, the credibility of strategies plays an important role in determining firms' incentives to introduce a new product in the market.

We now turn to innovation case c, shown in Table 2.1.

High Quality Innovation by the Low Quality Firm (Case c)

Product Market Competition - Stage 3: Prices, demand, and profits are analogous to previous cases adjusted for the corresponding product qualities.[16]

Number of Products - Stage 2: In this stage, each firm decides whether to keep or withdraw the original product from the market taking the rival's action into account. Their decision is a comparison of profits under both scenarios, as shown in equation (6).

We begin by investigating the low quality firms' marginal profits (stage 3) with respect to its original product quality.

When the high quality firm keeps its first product in the market after innovating, the low quality firm's best response is to withdraw the first product,

[14] A lower chosen equilibrium quality by the low quality firm in the accommodation case softens price competition and increases the high quality firm's revenues indexed by a higher 'x'.

[15] Table 2.3 shows firms' profits (stage 3) for the different choices in stage 2 and 1.

[16] Profits are shown in Appendix B.1, and in Siebert (1999), case c equation (39), case e equation (41), and Appendix 1.

see equation (14) in Appendix B.1. It benefits more by softening price competition (*first strategic effect*) instead of attracting more consumers (*demand effect*),

$$\frac{d\pi_1^{0,1}}{ds_1^0} = \underbrace{\overbrace{\frac{\partial \pi_1^{0,1}}{\partial D_1^0}}^{+}\overbrace{\frac{\partial D_1^0}{\partial p_2^0}}^{+}\overbrace{\frac{dp_2^0}{ds_1^0}}^{-}}_{\textit{first strategic effect}} + \underbrace{\overbrace{\frac{\partial \pi_1^{0,1}}{\partial D_1^1}}^{+}\overbrace{\frac{\partial D_1^1}{\partial p_2^0}}^{+}\overbrace{\frac{dp_2^0}{ds_1^0}}^{-}}_{\textit{second strategic effect}} + \underbrace{\overbrace{\frac{\partial \pi_1^{0,1}}{\partial D_1^1}}^{+}\overbrace{\frac{\partial D_1^1}{\partial p_2^1}}^{+}\overbrace{\frac{dp_2^1}{ds_1^0}}^{-}}_{\textit{third strategic effect}} + \underbrace{\overbrace{\frac{\partial \pi_1^{0,1}}{\partial D_1^0}}^{+}\overbrace{\frac{\partial D_1^0}{ds_1^0}}^{+}}_{\textit{demand effect}} < 0. \tag{10}$$

When the high quality firm withdraws its first product from the market, the low quality firm is still better off to withdraw since it avoids cannibalizing its own product demand, see Siebert (1999), case e, equation (23), setting $s_2^1 = s_2^0$. As a result, the low quality firm has a dominant strategy to withdraw its first product.

Given the low quality firm's dominant strategy to withdraw, the high quality firm is better off to withdraw the original product as well in order to reduce price competition, see Siebert (1999), equation (18), setting $s_2^0 = s_2^1$, $s_1^1 = s_1^0$, and $s_2^1 = s_2^0$.

As a result, both firms withdraw their original products when they introduce a new product in the high quality area. Again, the high quality firm is not able to commit keeping the original product in the market in order to *deter* the low quality firm from introducing a new product in the high quality area.

We now turn to investigate the innovators' quality choice.

Quality Choice - Stage 1: The innovator's (firm i's) objective is to choose a product quality which maximizes profits, given by

$$\Pi_i^1\left(s_i^1, s_j^1\right) = \pi_i^1\left(s_i^1, s_j^1\right) - F_i\left(s_i^1\right). \tag{11}$$

Taking the innovator's first order condition of equation (11) with respect to its new product quality s_i^1 shows that the innovator's marginal profits (stage 3) are positive (see Siebert [1999], Appendix 1, equation (33) and (34) setting $s_1^1 = s_1^0$ and $s_2^1 = s_2^0$). Whether a firm has an incentive to introduce a new product is a comparison of profits when it introduces a new product with the profits when it does not introduce a new product which depends on the R&D costs for quality, as shown in equation (8).

We can summarize case c with the following result: Firms' decision to introduce a new product in the high quality area depends on the R&D costs. Both innovators withdraw their original product from the market.

After analyzing the innovation scenario when the high quality firm offers the highest product quality (cases a, b, and c), we can conclude with the following proposition.

Proposition 2 *When the high quality firm offers a new product with highest quality, the low quality firm may introduce a new product in the intermediate, or in the high quality area, depending on the R&D costs. Both innovators withdraw their original product from the market.*

When the low quality firm offers the highest product quality, as illustrated in Table 2.2, we can show that no candidate equilibrium exists. A detailed analysis of cases d to f is described in Appendix B.

After analyzing all the innovation cases (a to f) we can derive the following result:

When innovation occurs simultaneously, both firms introduce a new product of higher quality. The high quality firm introduces a new product with highest quality in the high quality area, whereas the low quality firm introduces a new product either in the intermediate or in the high quality area. Furthermore, both firms withdraw their original product from the market. As a result, the high quality firm's strategy to deter or preempt the innovation by the low quality firm is not credible.

3 Conclusion

In this study we analyze a model of two incumbent firms, which simultaneously may introduce a new product in a vertically differentiated market. We examine firms' incentives to introduce new products of different quality into the market and analyze if they keep or withdraw their first product from the market. We analyze the variety of products and the quality level of the products offered in the market.

We show that product innovation depends on the credibility of firms' innovation strategies. Therefore, the high quality firm's strategy to preempt (deter) the low quality firm's innovation is not credible. The high quality firm always chooses a quality according to the accommodation strategy. Firms introduce a higher quality at a higher price in order to concentrate their sales on high income consumers. More precisely, the high quality firm introduces a new product with highest quality in the high quality area, whereas the low quality firm introduces a new product either in the intermediate or in the high quality area. The innovators always withdraw their original product in order to reduce price competition and not to cannibalize its original product demand.

This study shows that the outcome of new product introduction in models of vertical differentiation depends on the credibility of firms' innovation strategies and is similar to Judd (1985) for horizontal models.

4 APPENDIX

Appendix A

The Low Quality Firm Offers the Highest Product Quality

When the low quality firm offers the highest product quality, the high quality firm has the opportunity to introduce a new product in the low quality area (case d), in the intermediate quality area (case e), or in the high quality area (case f). We will first analyze case d.

Low Quality Innovation by the High Quality Firm (Case d)

Product Market Competition - Stage 3: The results are determined by the innovators' decision to keep or withdraw their original product and are shown in Appendix B.1, in case a (Siebert [1999], equation (4)), in case e (Siebert [1999], equation (41)), and in Siebert (1999), Appendix 1, adjusted for the corresponding product qualities.

Number of Products - Stage 2 and Quality Choice - Stage 1: In this innovation case, the products offered by firms are ranked in alternating order, see Table 2.2. When a firm's product quality is located between two of the rival's products, price competition reduces prices and profits to zero when product qualities are identical. Firms' profits begin to increase as the product quality moves apart but decrease to zero again when the product quality approaches the other rival's product. Firms' marginal profits are not monotonic in- or decreasing with respect to the original product quality. As a consequence, analyzing firms' decision to keep or withdraw the original product (stage 2) by investigating firms' marginal profits does not work. Another opportunity might be to compare profits when a firm keeps the original product with the profits when it withdraws the product from the market. But this procedure is based on comparing polynomials of high degrees which is computationally not tractable. These difficulties prevent us from solving the game backwards. Therefore, we solve this case by investigating stage 1 and 2, simultaneously.

We first analyze the low quality firm's decision to keep or withdraw the original product from the market (stage 2) by taking the high quality firm's choice from stage 2 and stage 1 into account.

Suppose both firms keep the first product in the market. Equation (15) in Appendix B.1 shows that the high quality firm has no incentive to introduce a new product in the low quality area. It benefits more by not innovating and taking advantage of a lower price competition towards the low quality firm's first product (first strategic effect) instead of introducing a new product in the low quality area and profiting from a higher demand effect. The effects are shown in the following equation

$$\frac{d\pi_2^{1,0}}{ds_2^1} = \underbrace{\overbrace{\frac{\partial \pi_2^{1,0}}{\partial D_2^1}}^{+}\overbrace{\frac{\partial D_2^1}{\partial p_1^0}}^{+}\overbrace{\frac{dp_1^0}{ds_2^1}}^{-}}_{\textit{first strategic effect}} + \underbrace{\overbrace{\frac{\partial \pi_2^{1,0}}{\partial D_2^0}}^{+}\overbrace{\frac{\partial D_2^0}{\partial p_1^0}}^{+}\overbrace{\frac{dp_1^0}{ds_2^1}}^{-}}_{\textit{second strategic effect}} + \underbrace{\overbrace{\frac{\partial \pi_2^{1,0}}{\partial D_2^0}}^{+}\overbrace{\frac{\partial D_2^0}{\partial p_1^1}}^{+}\overbrace{\frac{dp_1^1}{ds_2^1}}^{-}}_{\textit{third strategic effect}} + \underbrace{\overbrace{\frac{\partial \pi_2^{1,0}}{\partial D_2^1}}^{+}\overbrace{\frac{\partial D_2^1}{ds_2^1}}^{+}}_{\textit{demand effect}} < 0. \tag{12}$$

When the high quality firm does not introduce a new product in the low quality area the best action for the low quality firm is to withdraw the original product from the market, see equation (18).

Suppose the high quality firm withdraws the original product after innovating in the low quality area. Three products with qualities $s_2^1 < s_1^0 < s_1^1$ are offered in the market. The low quality firm's best response is to withdraw the original product from the market in order to avoid cannibalizing its own product demand and to relax price competition, see equation (9), setting $s_2^1 = s_1^0$, $s_1^0 = s_2^0$, and $s_1^1 = s_2^1$. As a result, the low quality firm is always better off withdrawing the original product from the market when it introduces a new product in the high quality area.

We now analyze the high quality firm's decision to keep or withdraw the original product from the market (according to equation (6)) and its quality decision (according to equation (7)) given the low quality firm's choices.

The high quality firm's decision to keep or withdraw the original product depends on the extent of the low quality firm's innovation (see Siebert [1999], Appendix 1, setting $s_2^1 = s_1^0$ and $s_1^1 = s_2^0$).

When the low quality firm's innovation is large ($s_1^1 \geq \frac{7}{4}s_2^0$), the high quality firm keeps the original product in the market and does not introduce a new product in the low quality area, see equation (18). Withdrawing and introducing a new product in the low quality area is not optimal, because the high quality firm would earn higher profits by increasing its new product quality up to its original product quality s_2^0, see Siebert (1999) equation (33), Appendix 1, setting $s_2^1 = s_1^0$ and $s_1^1 = s_2^0$.

When the low quality firm's innovation is only small ($s_1^1 < \frac{7}{4}s_2^0$), a tougher price competition towards the high quality firm's first product is initialized. The high quality firm's best response is to withdraw the first product from the market and to introduce a new product in the low quality area in order to soften price competition.

Two products remain in the market in this innovation case. However, we know from equations (33) and (34) (see Siebert [1999], Appendix 1 setting $s_1^1 = s_2^0$ and $s_2^1 \wedge s_2^0 = s_1^0$) that the high quality firm earns higher profits than the low quality firm. Taking into account that firms' costs functions are symmetric, we can conclude that the high quality firm is better off providing a product with highest product quality.

Finally, we can summarize case d with the following result: When the low quality firm offers a new product in the high quality area, the high quality firm is better off to introduce a new product of higher quality instead of offering a new product in the low quality area.

Intermediate Quality Innovation by the High Quality Firm (Case e)

Product Market Competition - Stage 3: The results are shown in Appendix B.2, in case c (Siebert [1999], equation (39)), in case e (Siebert [1999], equation (41)),and in Siebert (1999), Appendix 1, adjusted for the corresponding qualities.

Number of Products - Stage 2: For computational reasons, we investigate firms' marginal profits (stage 3) with respect to the original product quality. We begin with analyzing the low quality firm's decision in stage 2 given any decision of the high quality firm.

When the high quality firm keeps the original product in the market, the low quality firm's best response is to withdraw the first product. Equation (16) in Appendix B.2 and equation (13) show that the low quality firm benefits more from softening price competition (second strategic effect) instead of attracting more consumers (demand effect),

$$\frac{d\pi_1^{0,1}}{ds_1^0} = \underbrace{\overbrace{\frac{\partial \pi_1^{0,1}}{\partial D_1^0}}^{+}\overbrace{\frac{\partial D_1^0}{\partial p_2^1}}^{+}\overbrace{\frac{dp_2^1}{ds_1^0}}^{-}}_{\textit{first strategic effect}} + \underbrace{\overbrace{\frac{\partial \pi_1^{0,1}}{\partial D_1^1}}^{+}\overbrace{\frac{\partial D_1^1}{\partial p_2^0}}^{+}\overbrace{\frac{dp_2^0}{ds_1^0}}^{-}}_{\textit{second strategic effect}} + \underbrace{\overbrace{\frac{\partial \pi_1^{0,1}}{\partial D_1^0}}^{+}\overbrace{\frac{\partial D_1^0}{\partial s_1^0}}^{+}}_{\textit{demand effect}} < 0. \tag{13}$$

When the high quality firm withdraws, the low quality firm is better off to withdraw as well, see Siebert (1999), equation (18). We can conclude that the low quality firm has a dominant strategy to withdraw the original product from the market.

Given the low quality firm's dominant strategy to withdraw the original product from the market the high quality firm's decision in stage 2 depends on the low quality firm's quality decision in stage 1. The argument is similar to case f in Siebert (1999) with $s_2^1 = s_1^1$, $s_2^0 = s_1^0$, and $s_1^1 = s_2^0$. When the leapfrog innovation by the low quality firm is sufficiently high, such that the new product quality satisfies $s_1^1 > \frac{7}{4}s_2^0$ the high quality firm's marginal profits are positive. The high quality firm keeps the original product in the market. When the leapfrog innovation by the low quality firm is small $s_1^1 < \frac{7}{4}s_2^0$, the high quality firm's marginal profits are negative and the high quality firm is better off to withdraw the original product.

As a result, the low quality firm withdraws the original product after innovating whereas the high quality firm's choice to keep or withdraw the original product from the market depends on the low quality firm's extent of innovation. Let us now turn to investigate the firms' quality choice.

Quality Choice - Stage 1: The innovators' quality decision in stage 1 is analyzed according to their objective function (7).

When the low quality firm's innovation is large, the high quality firm keeps its original product in the market and does not introduce a new product in the intermediate quality area because it cannibalizes the high quality firm's own product demand, see equation (31), setting $s_2^1 = s_1^1$, $s_2^0 = s_1^0$, and $s_1^1 = s_2^0$.

When the low quality firm's innovation is small, a tougher price competition towards the high quality firm's first product is initialized. The high quality firm's best response is to withdraw the first product from the market and to introduce a new product in the intermediate quality area in order to soften price competition, see Siebert (1999), Appendix 1, equation (33).

However, we know from case d that the high quality firm earns higher profits by introducing a new product of highest quality (see equations (33) and (34), Appendix 1, in Siebert (1999), setting $s_1^1 = s_2^0$ and $s_2^1 \wedge s_2^0 = s_1^0$, and taking into account that firms' costs functions are symmetric).

Finally, we can summarize case e with the following result: When the low quality firm offers a new product in the high quality area, the high quality firm is better off to introduce a new product of higher quality instead of offering a new product in the intermediate quality area.

High Quality Innovation by the High Quality Firm (Case f)

Product Market Competition - Stage 3: The results are shown in Appendix B.2, in equation (41), in equation (39), and in Siebert (1999), Appendix 1, adjusted for the corresponding qualities.

Number of Products - Stage 2: When the high quality firm keeps the first product in the market the low quality firm's best response is to withdraw the first product, see equation (13), setting $s_2^1 = s_2^0$ and vice versa.

When the high quality firm withdraws the first product from the market the low quality firm will withdraw as well in order to soften price competition, see equation (18), adjusted for $s_2^1 = s_2^0$.

As a result, the low quality firm has a dominant strategy to withdraw the first product from the market. Given the low quality firm's dominant strategy, the high quality firm withdraws the original product as well, see equation (23), setting $s_2^0 = s_1^0$, $s_2^1 = s_1^1$, and $s_1^1 = s_2^0$.

Finally, both firms offer a new product in the high quality area and withdraw their original product from the market. Two products with qualities $s_2^1 < s_1^1$ remain in the market

Quality Choice - Stage 1: As we know from case d, this innovation case is not optimal for the high quality firm since it earns higher profits by introducing a new product of higher quality than the low quality firm.

After analyzing the innovation cases d, e and f, we can conclude with the following proposition.

When the low quality firm offers a new product in the high quality area the high quality firm introduces a new product with higher quality. Both innovators withdraw the original product.

Appendix B

B.1: High Quality Innovation by the Low Quality Firm and Low Quality Innovation by the High Quality Firm (Case d)

The low quality firm offers a new product in the high quality area, whereas the high quality firm introduces a new product in the low quality area. Both firms keep their original products in the market. We get the following sequence of qualities $s_2^1 < s_1^0 < s_2^0 < s_1^1$.
For demand we get

$$D_2^1\left(p_2^1, p_1^0, s_2^1, s_1^0\right) = \frac{\left(p_1^0 - p_2^1\right)}{\left(s_1^0 - s_2^1\right)} - \frac{p_2^1}{s_2^1},\ D_1^0\left(p_2^1, p_1^0, p_2^0, s_2^1, s_1^0, s_2^0\right) = \frac{\left(p_2^0 - p_1^0\right)}{\left(s_2^0 - s_1^0\right)} - \frac{\left(p_1^0 - p_2^1\right)}{\left(s_1^0 - s_2^1\right)},$$

$$D_2^0\left(p_1^0, p_2^0, p_1^1, s_1^0, s_2^0, s_1^1\right) = \frac{\left(p_1^1 - p_2^0\right)}{\left(s_1^1 - s_2^0\right)} - \frac{\left(p_2^0 - p_1^0\right)}{\left(s_2^0 - s_1^0\right)}, \text{ and } D_1^1\left(p_2^0, p_1^1, s_2^0, s_1^1\right) = 1 - \frac{\left(p_1^1 - p_2^0\right)}{\left(s_1^1 - s_2^0\right)}.$$

Both firms maximize their profits with respect to their product prices. For the reaction functions we get

$$p_2^1\left(p_1^0\right) = \frac{p_1^0 s_2^1}{2s_1^0},\ p_1^0\left(p_2^0, p_2^1\right) = \frac{p_2^0\left(s_1^0 - s_2^1\right) + p_2^1\left(s_2^0 - s_1^0\right)}{2\left(s_2^0 - s_1^0\right)},$$

$$p_2^0\left(p_1^1, p_1^0\right) = \frac{p_1^1\left(s_2^0 - s_1^0\right) + p_1^0\left(s_1^1 - s_2^0\right)}{2\left(s_1^1 - s_1^0\right)}, \text{ and } p_1^1\left(p_2^0\right) = \frac{p_2^0 + s_1^1 - s_2^0}{2}.$$

As we can see, the reaction functions are strictly monotone and have a unique Nash equilibrium. We get for the corresponding equilibrium prices

$$p_2^1(s_2^1, s_1^0, s_2^0, s_1^1) = \frac{s_2^1\left(s_2^1 - s_1^0\right)\left(s_1^0 - s_2^0\right)\left(s_2^0 - s_1^1\right)}{\Omega},$$

$$p_1^0(s_2^1, s_1^0, s_2^0, s_1^1) = \frac{2s_1^0\left(s_2^1 - s_1^0\right)\left(s_1^0 - s_2^0\right)\left(s_2^0 - s_1^1\right)}{\Omega},$$

$$p_2^0(s_2^1, s_1^0, s_2^0, s_1^1) = \frac{\left(s_1^0 - s_2^0\right)\left(4s_1^0 s_2^0 - s_2^1\left(3s_1^0 + s_2^0\right)\right)\left(s_2^0 - s_1^1\right)}{\Omega},$$

$$p_1^1(s_2^1, s_1^0, s_2^0, s_1^1) = \frac{1}{2}\left\{s_1^1 - s_2^0 + \frac{\left(s_1^0 - s_2^0\right)\left(4s_1^0 s_2^0 - s_2^1\left(3s_1^0 + s_2^0\right)\right)\left(s_2^0 - s_1^1\right)}{\Omega}\right\}.$$

For demand we get

$$D_2^1(s_2^1, s_1^0, s_2^0, s_1^1) = \frac{s_1^0\left(s_1^0 - s_2^0\right)\left(s_2^0 - s_1^1\right)}{\Omega},\ D_1^0(s_2^1, s_1^0, s_2^0, s_1^1) = \frac{2s_1^0\left(s_2^1 - s_2^0\right)\left(s_2^0 - s_1^1\right)}{\Omega},$$

$$D_2^0(s_2^1, s_1^0, s_2^0, s_1^1) = \frac{\left(s_2^1\left(3s_1^0 + s_2^0\right) - 4s_1^0 s_2^0\right)\left(s_1^0 - s_1^1\right)}{\Omega},$$

$$D_1^1(s_2^1, s_1^0, s_2^0, s_1^1) = \frac{2\left(s_2^1\left(3{s_1^0}^2 - 2s_1^0 s_1^1 - s_2^0 s_1^1\right) - s_1^0\left(s_1^0\left(3s_2^0 + s_1^1\right) - 4s_2^0 s_1^1\right)\right)}{\Omega},$$

where
$\Omega = s_2^1\left(9{s_1^0}^2 + 2s_1^0\left(s_2^0 - 4s_1^1\right) + s_2^0\left(s_2^0 - 4s_1^1\right)\right) - 4s_1^0\left(s_2^0\left(s_2^0 - 4s_1^1\right) + s_1^0\left(2s_2^0 + s_1^1\right)\right).$
Profits are

$$\pi_2^1(s_2^1, s_1^0, s_2^0, s_1^1) = \frac{s_2^1 s_1^0\left(s_1^0 - s_2^1\right)\left(s_1^0 - s_2^0\right)^2\left(s_2^0 - s_1^1\right)^2}{\Omega^2},$$

$$\pi_2^0(s_2^1, s_1^0, s_2^0, s_1^1) = \frac{\left(s_2^0 - s_1^0\right)\left(s_2^1\left(3s_1^0 + s_2^0\right) - 4s_1^0 s_2^0\right)^2\left(s_1^0 - s_1^1\right)\left(s_2^0 - s_1^1\right)}{\Omega^2},$$

$$\pi_1^0(s_2^1, s_1^0, s_2^0, s_1^1) = \frac{4{s_1^0}^2\left(s_1^0 - s_2^1\right)\left(s_2^1 - s_2^0\right)\left(s_1^0 - s_2^0\right)\left(s_2^0 - s_1^1\right)^2}{\Omega^2}, \text{ and}$$

$$\pi_1^1(s_2^1, s_1^0, s_2^0, s_1^1) = \frac{4\left(s_1^1 - s_2^0\right)\left(s_2^1\left(2s_1^0 s_1^1 + s_2^0 s_1^1 - 3{s_1^0}^2\right) + s_1^0\left(s_1^0\left(3s_2^0 + s_1^1\right) - 4s_2^0 s_1^1\right)\right)^2}{\Omega^2}.$$

The partial derivative of the low quality firm's profits with respect to s_1^0 is given by

$$\frac{\partial \pi_1^{0,1}}{\partial s_1^0} = -\frac{49\left(9s_2^0 - 16s_1^1\right)\left(s_2^0 - s_1^1\right)^2\left(s_2^0 - s_2^1\right)\left(s_1^1 - s_2^1\right)^2}{48\left(3{s_2^0}^2 - 4s_2^0 s_1^1 - 2{s_1^1}^2 - 5s_2^0 s_2^1 + 8s_1^1 s_2^1\right)^3} < 0. \tag{14}$$

The partial derivative of the high quality firm's profits with respect to s_2^1 is given by

$$\frac{\partial \pi_2^{1,0}}{\partial s_2^1} = \frac{48{s_2^0}^2\left(s_2^0 - s_1^1\right)^2\left(-137s_2^1 s_2^0 + 144{s_2^0}^2 + 252s_2^1 s_1^1 - 256s_2^0 s_1^1\right)}{\left(83s_2^1 s_2^0 - 80{s_2^0}^2 - 140s_2^1 s_1^1 + 128s_2^0 s_1^1\right)^3} < 0. \tag{15}$$

B.2: High Quality Innovation by the Low Quality Firm and Intermediate Quality Innovation by the High Quality Firm (Case e)

When the low quality firm introduces a new product in the high quality area and the high quality firm introduces a new product in the intermediate quality area, we get the following sequence of qualities $s_1^0 < s_2^1 < s_2^0 < s_1^1$.
For demand we get

$$D_1^0\left(p_1^0, p_2^1, s_1^0, s_2^1\right) = \frac{\left(p_2^1 - p_1^0\right)}{\left(s_2^1 - s_1^0\right)} - \frac{p_1^0}{s_1^0},\ D_2^1\left(p_1^0, p_2^1, p_2^0, s_1^0, s_2^1, s_2^0\right) = \frac{\left(p_2^0 - p_2^1\right)}{\left(s_2^0 - s_2^1\right)} - \frac{\left(p_2^1 - p_1^0\right)}{\left(s_2^1 - s_1^0\right)},$$

$$D_2^0\left(p_2^1, p_2^0, p_1^1, s_2^1, s_2^0, s_1^1\right) = \frac{\left(p_1^1 - p_2^0\right)}{\left(s_1^1 - s_2^0\right)} - \frac{\left(p_2^0 - p_2^1\right)}{\left(s_2^0 - s_2^1\right)}, \text{ and } D_1^1\left(p_2^0, p_1^1, s_2^0, s_1^1\right) = 1 - \frac{\left(p_1^1 - p_2^0\right)}{\left(s_1^1 - s_2^0\right)}.$$

Both firms maximize their profits with respect to their product prices. For the reaction functions we get

$$p_1^0\left(p_2^1\right)=\frac{p_2^1 s_1^0}{2s_2^1},\ p_2^1\left(p_2^0,p_1^0\right)=\frac{2p_2^0\left(s_2^1-s_1^0\right)+p_1^0\left(s_2^0-s_2^1\right)}{2\left(s_2^0-s_1^0\right)},\ p_2^0\left(p_1^1,p_1^0\right)=\frac{p_1^1\left(s_2^0-s_1^0\right)+p_1^0\left(s_1^1-s_2^0\right)}{2\left(s_1^1-s_1^0\right)},$$

and

$$p_1^1\left(p_2^0\right)=\frac{p_2^0+s_1^1-s_2^0}{2}.$$

As we can see, the reaction functions are strictly monotone and have a unique Nash equilibrium. We get for the corresponding equilibrium prices

$$p_1^0(s_1^0,s_2^1,s_2^0,s_1^1)=\frac{2s_1^0\left(s_1^0-s_2^1\right)\left(s_2^0-s_1^1\right)}{\Phi},\ p_2^1(s_1^0,s_2^1,s_2^0,s_1^1)=\frac{4s_2^1\left(s_1^0-s_2^1\right)\left(s_2^0-s_1^1\right)}{\Phi},$$

$$p_2^0(s_1^0,s_2^1,s_2^0,s_1^1)=\frac{\left(4s_2^1s_2^0-s_1^0\left(3s_2^1+s_2^0\right)\right)\left(s_2^0-s_1^1\right)}{\Phi},\text{ and}$$

$$p_1^1(s_1^0,s_2^1,s_2^0,s_1^1)=\frac{2\left(s_2^0-s_1^1\right)\left(-4s_2^1s_1^1+s_1^0\left(3s_2^1+s_1^1\right)\right)}{-\Phi}.$$

Demand is

$$D_1^0(s_1^0,s_2^1,s_2^0,s_1^1)=\frac{2s_2^1\left(s_2^0-s_1^1\right)}{\Phi},\ D_2^1(s_1^0,s_2^1,s_2^0,s_1^1)=\frac{s_1^0\left(s_2^0-s_1^1\right)}{\Phi},$$

$$D_2^0(s_1^0,s_2^1,s_2^0,s_1^1)=\frac{\left(-4s_2^1s_1^1+s_1^0\left(3s_2^1+s_1^1\right)\right)}{\Phi},\text{ and}$$

$$D_1^1(s_1^0,s_2^1,s_2^0,s_1^1)=\frac{2\left(-4s_2^1s_1^1+s_1^0\left(3s_2^1+s_1^1\right)\right)}{\Phi}.$$

Profits are

$$\pi_1^{0,1}(s_1^0,s_2^1,s_2^0,s_1^1)=\frac{4s_1^0s_2^1\left(s_2^1-s_1^0\right)\left(s_2^0-s_1^1\right)^2}{\Phi^2}+\frac{4\left(s_1^1-s_2^0\right)\left(-4s_2^1s_1^1+s_1^0\left(3s_2^1-s_1^1\right)\right)^2}{\Phi^2},\text{ and}$$

$$\pi_2^{1,0}(s_1^0,s_2^1,s_2^0,s_1^1)=\frac{4s_1^0s_2^1\left(s_2^1-s_1^0\right)\left(s_2^0-s_1^1\right)^2}{\Phi^2}+\frac{\left(4s_2^1s_2^0-s_1^0\left(3s_2^1+s_2^0\right)\right)\left(s_2^0-s_1^1\right)\left(-4s_2^1s_1^1-s_1^0\left(3s_2^1-s_1^1\right)\right)}{\Phi^2},$$

where

$$\Phi=4s_2^1\left(s_2^0-4s_1^1\right)+s_1^0\left(9s_2^1-s_2^0+4s_1^1\right).$$

The partial derivative of the low quality firm's profits with respect to s_1^0 is given by

$$\frac{\partial \pi_1^{0,1}}{\partial s_1^0} = \frac{4s_2^{0^2}\left(s_2^1 - s_1^1\right)^2\left(s_1^0\left(-81s_2^0 - 7s_2^1 + 4s_1^1\right) + 4s_2^0\left(s_2^1 + 20s_1^1\right)\right)}{\left(4s_2^0\left(s_2^1 - 4s_1^1\right) + s_1^0\left(9s_2^0 - s_2^1 + 4s_1^1\right)\right)^3} < 0. \tag{16}$$

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