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**Working Paper**

## New product introduction by incumbent firms

WZB Discussion Paper, No. FS IV 99-19r

**Provided in Cooperation with:**

WZB Berlin Social Science Center

*Suggested Citation:* Siebert, Ralph (2003) : New product introduction by incumbent firms, WZB Discussion Paper, No. FS IV 99-19r, Wissenschaftszentrum Berlin für Sozialforschung (WZB), Berlin

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**discussion papers**

**The Impact of R&D Subsidies on the  
Introduction of New Products by  
Incumbent Firms**

Ralph Siebert

Revision: August 2003

This is a *revision* of discussion paper [FS IV 99-19](#)  
“*New Product Introduction by Incumbent Firms*”

# The Impact of R&D Subsidies on the Introduction of New Products by Incumbent Firms

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July, 2003

## Abstract

This paper analyzes the impact of R&D subsidies on incumbent firms to introduce new goods. We are especially interested in investigating various consequences of government subsidies for R&D, provided to firms that offer products of different qualities. This study examines the incentives of incumbent firms to introduce new products of various quality, their prices, as well as the product variety offered on the market. We find that the innovator always introduces a new product of higher quality and withdraws the existing product from the market. Providing an R&D subsidy to a high-quality firm results in a new product with higher quality than an R&D subsidy provided to a low-quality firm, at the expense of all consumers paying higher prices for all goods in the market. When the R&D subsidy is small, the low quality firm may not introduce a new product into the market, given that R&D costs for quality improvement are high and the degree of product differentiation is small.

JEL: L11, L13, L52, O31, O32, O38.

Keywords: Asymmetric Firms, Innovation, New Product Introduction, Subsidies, Technology Policy, Vertical Product Differentiation.

Acknowledgements: I am grateful to Mark Armstrong, Heidrun Hoppe, Dan Kovenock, Massimo Motta, William Novshek, Lars-Hendrik Röller, Armin Schmutzler, Margaret Slade, Jacques Thisse, Christian Wey and two anonymous referees for helpful comments and suggestions. I would also like to thank the EARIE 2001 for awarding this study with the "Young Economists' Price". I am very grateful to the "VolkswagenStiftung" for financial support. All remaining errors are my own.

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# 1 Introduction

Many R&D intensive industries are characterized by oligopolistic competition in vertically differentiated markets.<sup>1</sup> Prominent examples are the electronics and telecommunications equipment industry, which are strongly driven by a high pace of technological progress and fierce international competition. In these industries, incumbents frequently introduce new improved products of higher quality and often withdraw existing models from the market.<sup>2</sup> For instance, new PCs with faster processors, new cellular phones with longer ‘stand by time’, and new VCRs, DVDs or MP3 players are introduced into the market, while existing products are withdrawn.

Competition authorities are well aware of the fact, that innovation is one of the main driving forces determining the competitiveness of an industry. Government-industry R&D programs designed to subsidize firms’ R&D, have become increasingly common in recent years, see, e.g., Cohen and Noll (1995) and Stiglitz (1988). The aim of these programs is to promote “national champions” in order to keep current pace with international competition and ensure higher product quality. One prominent U.S. technology program is the Small Business Innovation Research Program (SBIR), which provides more than U.S. \$ 1 billion for R&D subsidies per year to small firms.<sup>3</sup> Sematech (Semiconductor Manufacturing Technology), a U.S. government sponsored R&D consortium, has been established to facilitate an innovative environment that fasters better products to consumers. To further improve the performance of innovation, the European Union enacted the Sixth Framework Program in 2002. Japan enacted the VLSI (Very Large Scale Integrated Circuits) program to promote innovative research that is both useful and commercially viable.

By how much consumers benefit from R&D subsidies, not only depends on the quality and prices of the new products introduced, but also on existing product prices and the variety already in the market. Decisions regarding existing products are often a matter of cannibalization, as well as demand and price effects, which have quite a variable impact on firms, see Aron and Lazear (1990). Consequently, firms’ incentives to introduce new products might differ considerably. Government authorities are concerned about optimal incentive schemes to firms, as these influence consumer welfare, such as product qualities, prices, and the variety offered in the market, when providing R&D grants to different firms.

This study provides insight into the introduction of new products by incumbents operating in vertically differentiated markets. The purpose of this study is to investigate the consequences of an R&D subsidy provided to different firms to improve the product quality, price and variety offered in the market.

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<sup>1</sup>We focus on a pure vertical product differentiation setting, as originated by Gabszewicz and Thisse (1979) and Shaked and Sutton (1982), in which consumers have identical taste and rank qualities in the same order. However, consumers decide to buy different goods, since they differ in their income. For more recent contributions in this area, see Hoppe and Lee (2003), Hoppe and Lehmann-Grube (2001) and Lehmann-Grube (1997) as well as the literature cited therein.

<sup>2</sup>There is a large body of recent empirical work focusing on the introduction of new products. Prominent examples are Berry, Levinsohn, and Pakes (1993), Berry and Waldvogel (1999), Davis (2002), Hausman (1997) and Petrin (2002).

<sup>3</sup>For more information on this program, see Lerner (1999) and Wallsten (2000).

We present a duopoly model in which incumbents may introduce a new product with a certain quality. The innovator may keep or withdraw the existing product from the market and firms can set product prices. The research shows that firms introduce a new product of higher quality than the existing product. In terms of product variety, this study confirms that the basic result by Champsaur and Rochet (1989), established in a horizontal product differentiation setting, also holds in a pure vertical differentiation model.<sup>4</sup> Firms will differentiate their product lines from those of their competitors, according to the principle of ‘maximal product differentiation’ as developed by Shaked and Sutton (1982). Innovators withdraw existing products close to those of competitors in order to soften price competition. Interestingly, in a vertical product differentiation setting with uniformly distributed preferences, this principle is even stronger, as innovators will even withdraw products close to their own products. Firms fare better if they do not offer a range or interval of product qualities in markets characterized by vertical product differentiation, in order to avoid cannibalizing their new product’s demand. If no room is left for discrimination, innovators earn higher profits despite offering a smaller variety of goods. Note that this result also contributes to the ‘damaged goods’ literature that is frequently based on vertical differentiation settings which assume a bimodal distribution of preferences. This literature suggests that firms might be able to proliferate the product space, see, e.g., Deneckere and McAfee (1996) and Johnson and Myatt (2002). The fundamental result that innovators withdraw existing products enables us to evaluate the impact of R&D subsidies when provided to different firms.

An R&D subsidy provided to a high-quality firm, results in higher industry quality and higher ‘quality adjusted’ prices for all product prices in the market, since withdrawing the existing product results in a higher degree of product differentiation that tends to soften price competition. Therefore, when a high-quality firm introduces a higher level of quality, it does so at the expense of *all* consumers paying higher prices in the market.

An R&D subsidy provided to a low-quality firm is ambiguous. If the R&D subsidy is only small and the degree of product differentiation is large, a low-quality firm may introduce a new product of intermediate quality. However, if the degree of product differentiation is small, a low-quality firm may not introduce a new product into the market in order to avoid its products from becoming closer and therefore less distinguishable from a high-quality firm’s product. If the R&D subsidy is large, a low-quality firm may leapfrog over a firm’s high-quality product, while offering a lower industry quality at lower quality adjusted prices instead of providing the R&D subsidy to a high-quality firm, since the disparity between the product qualities is smaller.

The remainder of this paper is organized as follows. Section 2 describes our model of new product introduction to a vertical product differentiation setting. Section 3 rules out several subgames characterized by two adjacent products offered by the same firm. Section 4 analyzes a low-quality firm’s decision to introduce a

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<sup>4</sup>For further literature on product proliferation and entry deterrence, see, e.g. Schmalensee (1978) and Judd (1985) in horizontally differentiated product markets and Donnenfeld and Weber (1992 and 1995) in vertically differentiated markets with single product firms.

new product in the market and whether to keep or withdraw its existing product from the market. Section 5 investigates a high-quality firm's decision whether to introduce a new product. In Section 6, we analyze the effect of an R&D subsidy provided by a government agency to various firms. In Section 7, we conclude.

## 2 The Model

We consider an outset in which two firms ( $i = 1, 2$ ) each offer one product with quality  $\underline{s}$ ,  $\bar{s} \in \mathfrak{R}^+$  and  $\underline{s} < \bar{s}$ . Thus, firm 1 is designated as the low-quality provider and firm 2 as the high-quality provider.<sup>5</sup> One firm is able to introduce a new product into the market.<sup>6</sup> We can distinguish between two scenarios: the low-quality firm is the innovator, and the high-quality firm is the innovator. In the following, we model a three-stage game.

In the *first stage*, the innovator (firm  $i$ ) chooses the quality of its new product,  $s_i \in [0, \infty)$ . We can distinguish between three quality areas, depending on where the innovator locates its new product quality: a low-quality area ( $s_i < \underline{s}$ ), an intermediate-quality area ( $\underline{s} < s_i < \bar{s}$ ), and a high-quality area ( $s_i > \bar{s}$ ), see also Figure 1.

New Product Introduction by the Low-Quality Firm			Product Locations	New Product Introduction by the High-Quality Firm		
Case $a$	Case $b$	Case $c$		Case $d$	Case $e$	Case $f$
$s_1$			high-quality area	$s_2$		
$\bar{s}$	$\bar{s}$	$\bar{s}$	existing high-quality product	$\bar{s}$	$\bar{s}$	$\bar{s}$
	$s_1$		intermediate-quality area		$s_2$	
$\underline{s}$	$\underline{s}$	$\underline{s}$	existing low-quality product	$\underline{s}$	$\underline{s}$	$\underline{s}$
		$s_1$	low-quality area			$s_2$

**Figure 1:** The innovation cases

The innovator has to invest in R&D for producing a higher quality. The quality costs for firm  $i$ 's new product is given by the following cost function

$$F(s, s_i(\gamma), \gamma) = \begin{cases} \gamma (s_i - s)^2 & \text{for } s_i > s, \text{ and } s = \underline{s}, \bar{s} \text{ if } i = 1, 2 \text{ respectively} \\ 0 & \text{otherwise.} \end{cases}$$

where  $\frac{\partial F(\cdot)}{\partial s_i} > 0$ ,  $\frac{\partial^2 F(\cdot)}{\partial s_i^2} > 0$  and  $\lim_{s_i \rightarrow \infty} F'(\cdot) = \infty$ , for  $s_i > s$ . The parameter  $\gamma$  describes the convexity of the cost curve, or how costly it is for the firm to produce

<sup>5</sup>The outset is based on the model by Choi and Shin (1992) which is a modification of Shaked and Sutton (1982) where the version of Tirole (1992) is used. The outset and results are shown in Appendix 1.

<sup>6</sup>Since we will analyze the different impact of an R&D subsidy provided to different firms, we assume that only one firm is the innovator.

quality. Firm  $i$ 's choice on quality  $s_i$  is determined by the profits  $\pi_i$ , it earns in the product market and its R&D costs

$$s_i^*(\gamma) = \arg \max_{s_i} \{ \pi_i(\cdot, s_i(\gamma)) - F(\cdot, s_i(\gamma), \gamma) \}.$$

Firm  $i$ 's profits in stage 1 are composed of firm  $i$ 's profits in the product market minus its R&D costs,

$$\Pi_i(\cdot, s_i(\gamma), \gamma) = \pi_i(\cdot, s_i(\gamma)) - F(\cdot, s_i(\gamma), \gamma). \quad (1)$$

In the *second stage*, the innovator decides whether to keep or withdraw its existing product from the market. The innovator keeps the existing product in the market, if

$$\pi_i^k(\underline{s}, \bar{s}, s_i) - \pi_i^w(s, s_i) > 0 \quad (2)$$

where  $i = 1, 2$  and  $s = \bar{s}$  or  $\underline{s}$ , if  $i = 1$  or  $2$ , respectively;  $\pi_i^k$  and  $\pi_i^w$  denote firm  $i$ 's profits, when it keeps or withdraws the existing product, respectively. In terms of the number of products the following cases may occur: the innovator keeps the existing product in the market and three products are offered; the innovator withdraws the existing product from the market and two products are offered in the market.

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.<sup>7</sup> We distinguish between R&D costs depending on quality, and production costs being independent of quality. No entry is assumed to occur.

Consumers' preferences are given 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  $\theta$  is uniformly distributed over the interval  $[0, 1]$ .<sup>8</sup> The assumption on the income parameter results in a noncovered market, which means that 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 game by applying backward induction.

### 3 Two Adjacent Products offered in the Market

In the following, we rule out several subgames, characterized by an innovator offering two adjacent product qualities in the market, shown by cases  $b, c, d$  and  $e$  in Figure 1. We obtain the following result.

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<sup>7</sup>When the innovator keeps its existing product in the market it is allowed to internalize price competition among its own products. More precisely, it takes into account that a price change of one of its products has an impact on its other product.

<sup>8</sup>The assumption on a uniformly distributed income parameter is very reasonable for the electronics and telecommunications market. Another common assumption is the bimodal distribution, which is, especially used in the "damaged goods" literature. However, the uniform better describes the electronics and telecommunications market, as very low preference for intermediate quality goods is difficult to justify, at least for the markets under consideration.

**Proposition 1** *A firm offering two adjacent product qualities in the market always withdraws the product with lower quality from the market.*

The proof of Proposition 1 is shown in Appendix 2. We can explicitly rule out the stage 1 subgames for the innovation cases  $c$ ,  $e$ , and  $f$ , in which a firm may introduce a new product with lower quality, as well as the stage 2 subgames for cases  $b$  and  $d$ , in which an innovator may keep the existing product in the market.

## 4 New Product Introduction by the Low-Quality Firm

In this chapter, we analyze when the low-quality firm introduces a new product in the high-quality area (case  $a$ ).

### 4.1 High-Quality Innovation by the Low-Quality Firm

In what follows, we investigate the product market competition (stage 3) in section 4.1.1 and derive demand, prices and profits. Section 4.1.2 investigates the innovator's choice to keep or withdraw the existing product (stage 2). We analyze the innovator's decision on product quality (stage 1) in section 4.1.3.

#### 4.1.1 Product Market Competition - Stage 3

When the low-quality firm introduces a new product in the high-quality area, three products with qualities  $s_1 > \bar{s} > \underline{s}$  are offered in the market. Consequently, there are three indifferent consumers prevalent in the market. One of them is indifferent between buying the product with highest quality  $s_1$  or with second highest quality  $\bar{s}$  from the high-quality firm. The income parameter of this consumer is given by  $\theta_1 = \frac{(p_1 - \bar{p})}{(s_1 - \bar{s})}$ . The consumer who is indifferent between buying the high-quality firm's product with quality  $\bar{s}$  and the low-quality firm's existing product with quality  $\underline{s}$  is described by the income parameter  $\bar{\theta} = \frac{(\bar{p} - \underline{p})}{(\bar{s} - \underline{s})}$ , whereas the income parameter  $\underline{\theta} = \frac{\underline{p}}{\underline{s}}$  represents the consumer who is indifferent between buying the product with lowest quality from the low-quality firm and not buying at all. For the demand functions, we get

$$D_1(\bar{p}, p_1, \bar{s}, s_1) = \int_{\theta_1}^{\theta=1} f(\theta) d\theta = 1 - \frac{(p_1 - \bar{p})}{(s_1 - \bar{s})}, \quad (3)$$

$$\bar{D}(\underline{p}, \bar{p}, p_1, \underline{s}, \bar{s}, s_1) = \int_{\bar{\theta}}^{\theta_1} f(\theta) d\theta = \frac{(p_1 - \bar{p})}{(s_1 - \bar{s})} - \frac{(\bar{p} - \underline{p})}{(\bar{s} - \underline{s})}, \quad (4)$$



and

$$\underline{D}(\underline{p}, \bar{p}, \underline{s}, \bar{s}) = \int_{\underline{\theta}}^{\bar{\theta}} f(\theta) d\theta = \frac{(\bar{p} - \underline{p})}{(\bar{s} - \underline{s})} - \frac{\underline{p}}{\underline{s}}. \quad (5)$$

Firms' profit functions in stage 3 are given by

$$\pi_1^k(\underline{p}, \underline{D}, p_1, D_1) = \underline{p}\underline{D}(\cdot) + p_1 D_1(\cdot), \text{ and}$$

$$\bar{\pi}(\bar{p}, \bar{D}) = \bar{p}\bar{D}(\cdot).$$

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

$$\frac{\partial \bar{\pi}(\bar{p}, \bar{D})}{\partial \bar{p}} \equiv 0 \implies \bar{p}(\underline{p}) = \frac{p_1(\bar{s} - \underline{s}) + \underline{p}(s_1 - \bar{s})}{2(s_1 - \underline{s})}.$$

The first order condition for the low-quality firm with respect to its existing product price is given by

$$\frac{\partial \pi_1^k(\underline{p}, \underline{D}, p_1, D_1)}{\partial \underline{p}} \equiv 0 \implies \underline{p}(\bar{p}) = \frac{\bar{p}\underline{s}}{2\bar{s}},$$

and with respect to its new product price,

$$\frac{\partial \pi_1^k(\underline{p}, \underline{D}, p_1, D_1)}{\partial p_1} \equiv 0 \implies p_1(\bar{p}) = \frac{\bar{p} + s_1 - \bar{s}}{2}.$$

The reaction functions are strictly monotone. Solving the first order conditions yields the corresponding prices<sup>9</sup>

$$\underline{p}(\underline{s}, \bar{s}, s_1) = \frac{\underline{s}(\bar{s} - \underline{s})(\bar{s} - s_1)}{2\Psi}, \quad \bar{p}(\underline{s}, \bar{s}, s_1) = \frac{\bar{s}(\bar{s} - \underline{s})(\bar{s} - s_1)}{\Psi},$$

$$p_1(\underline{s}, \bar{s}, s_1) = \frac{(s_1 - \bar{s})}{2 \left( 1 + \frac{\bar{s}(\bar{s} - \underline{s})}{3\underline{s}\bar{s} + \underline{s}s_1 - 4\bar{s}s_1} \right)},$$

with  $\Psi = 2\underline{s}\bar{s} + \bar{s}^2 + \underline{s}s_1 - 4\bar{s}s_1$ . Substituting these into equations (3), (4), and (5) gives us the equivalent demand

$$\underline{D}(\underline{s}, \bar{s}, s_1) = \frac{\bar{s}(\bar{s} - s_1)}{2\Psi}, \quad \bar{D}(\underline{s}, \bar{s}, s_1) = \frac{\bar{s}(\underline{s} - s_1)}{\Psi}, \text{ and}$$

$$D_1(\underline{s}, \bar{s}, s_1) = \frac{(\underline{s}(3\bar{s} + s_1) - 4\bar{s}s_1)}{2\Psi}.$$

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<sup>9</sup>For further information regarding the existence and uniqueness of Nash equilibria in discrete choice settings, see also Caplin and Nalebuff (1991).

Similarly, firms' profits in the product market are

$$\pi_1^k(\underline{s}, \bar{s}, s_1) = \frac{\underline{s}(\bar{s} - \underline{s})\bar{s}(\bar{s} - s_1)^2}{4\Psi^2} + \frac{(s_1 - \bar{s})(\underline{s}(3\bar{s} + s_1) - 4\bar{s}s_1)}{4\Psi \left(1 + \frac{\bar{s}(\bar{s} - \underline{s})}{(3\underline{s}\bar{s} + \underline{s}s_1 - 4\bar{s}s_1)}\right)} \quad (6)$$

and

$$\bar{\pi}(\underline{s}, \bar{s}, s_1) = \frac{\bar{s}^2(\bar{s} - \underline{s})(\underline{s} - s_1)(\bar{s} - s_1)}{\Psi^2}. \quad (7)$$

Equations (6) and (7) show that firms' profits (stage 3) depend on the product qualities and the number of products in the market. Note, in case the innovator withdraws its existing product, each firm offers one product and the results are analogous to the outset (see Appendix 1, adjusted for the corresponding product quality  $s_1 = \bar{s}$  and  $\bar{s} = \underline{s}$ ). In the following, we investigate the innovator's choice to keep or withdraw the existing product (stage 2).

#### 4.1.2 Keep or Withdraw - Stage 2

The innovator's decision to keep or withdraw the existing product is analyzed, as per equation (2). We need to compare profits after innovation when the low-quality firm keeps its product (equation (6)) with the case when it withdraws, see Appendix 1, equation (17), adjusted for  $s_1 = \bar{s}$  and  $\bar{s} = \underline{s}$ . However, solving for product qualities in closed form is not tractable, due to polynomials of higher order. For this reason, we implicitly analyze the innovator's decision to keep or withdraw the existing product from its marginal profits with respect to its existing product quality  $\underline{s}$ . We decompose the total derivative of the reduced-form profit function into several effects. The derivative of the low-quality firm's second-stage profit function with respect to its existing product quality  $\underline{s}$ , is given by

$$\begin{aligned} \frac{d\pi_1^k}{d\underline{s}} &= \underbrace{\frac{3\underline{s}\bar{s}^2(s_1 - \bar{s})^3}{2\Psi^3}}_{\text{first strategic effect}} + \underbrace{\frac{3\bar{s}^2(s_1 - \bar{s})^2(4\bar{s}s_1 - \underline{s}(3\bar{s} + s_1))}{2\Psi^3}}_{\text{second strategic effect}} + \\ &+ \underbrace{\frac{\bar{s}^2(s_1 - \bar{s})^2}{4(\bar{s}(\bar{s} - 4s_1) + \underline{s}(2\bar{s} + s_1))^2}}_{\text{demand effect}} < 0 \end{aligned} \quad (8)$$

with  $\Psi = 2\underline{s}\bar{s} + \bar{s}^2 + \underline{s}s_1 - 4\bar{s}s_1$ . Second-stage optimization, implies  $\frac{\partial \pi_1^k}{\partial p_1} = 0$  and  $\frac{\partial \pi_1^k}{\partial p} = 0$ . Thus, the effect of  $\underline{s}$  on  $\pi_1^k$  through the low-quality firm's price changes can be ignored by applying the envelope theorem. As shown in equation (8), both *strategic effects* dominate the *demand effect* resulting in a total negative effect.

The total derivative of the low-quality firm is negative, indicating that its profits continuously decrease in the quality of the existing product, which is equivalent to withdrawing the existing product from the market. The low-quality firm earns higher profits by withdrawing the existing product from the market in order to soften price competition, instead of keeping the existing product and gaining on demand. As a result, two products are offered in the market and the same results as in Appendix 1 apply, setting  $s_1 = \bar{s}$  and  $\bar{s} = \underline{s}$ .

### 4.1.3 Quality Choice - Stage 1

Next, we investigate the low-quality firm's choice on quality, given it withdraws the existing product from the market, as per equation (1). Taking the first order condition of the low-quality firm's first-stage profit function (1) with respect to its new product quality  $s_i$ , with  $i = 1$ , gives us<sup>10</sup>

$$\frac{\partial \Pi_i(s_j, s_i, \gamma)}{\partial s_i} = \frac{\partial \pi_i(s_j, s_i)}{\partial s_i} - 2\gamma(s_i - s) = 0 \quad (9)$$

for  $s_j = \bar{s}$  and  $s = \underline{s}$ . We implicitly differentiate the profit function (1) with respect to the cost parameter  $\gamma$  in order to derive the conditions on costs for introducing a new product in the high-quality area. Using the total derivative of the profit function with respect to  $\gamma$  and rearranging, gives

$$\begin{aligned} \frac{d\Pi_i(s, s_j, s_i(\gamma), \gamma)}{d\gamma} &= \frac{\partial s_i(\gamma)}{\partial \gamma} \left[ \frac{\partial \pi_i(s_j, s_i(\gamma))}{\partial s_i} - \frac{\partial F(s, s_i(\gamma), \gamma)}{\partial s_i} \right] \\ &\quad - \frac{\partial F(s, s_i(\gamma), \gamma)}{\partial \gamma}. \end{aligned} \quad (10)$$

As  $s_i(\gamma)$  is optimally chosen, such that it maximizes the innovator's profits we make use of the envelope theorem, given by

$$\frac{\partial \pi_i(s_j, s_i(\gamma))}{\partial s_i} - \frac{\partial F(s, s_i(\gamma), \gamma)}{\partial s_i} = 0. \quad (11)$$

Substituting equation (11) into equation (10), gives us

$$\frac{d\Pi_i(s, s_j, s_i(\gamma), \gamma)}{d\gamma} = -\frac{\partial F(s, s_i(\gamma), \gamma)}{\partial \gamma} = -(s_i - s)^2 < 0. \quad (12)$$

As we see in equation (12), the total derivative is equal to the partial derivative evaluated at the optimal choice of  $s_i$ . Finally, we only have to take into account the direct effect of an increase of  $\gamma$  on costs, but not the indirect effect via the choice

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<sup>10</sup>The innovator's objective function, equation (1), is concave in the low quality firm's new product quality  $s_i$ , because of the properties of the profit function (see Appendix 1, equation (22), setting  $s_i = \bar{s}$ ) and the cost function, such that a unique solution for  $s_i$  exists. See also Caplin and Nalebuff (1991) for existence and uniqueness of Nash equilibria in diverse discrete choice models.

of  $s_i$ . Equation (12) shows that the innovator's profits are continuously decreasing in  $\gamma$ . In other words, the innovator's stage 1 profits are higher, the lower the R&D production costs for quality. Setting  $\gamma = 0$  and inserting into equation (1), gives<sup>11</sup>

$$\Pi_i(s, s_j, s_i(\gamma), \gamma)|_{\gamma=0} = \pi_i(s_j, s_i(\gamma)) > \pi_i(\underline{s}, \bar{s}). \quad (13)$$

From equations (12) and (13) we can conclude that an unique  $\gamma = \gamma^0 > 0$  exists, such that  $\Pi_i(s, s_j, s_i(\gamma), \gamma)|_{\gamma^0} > \pi_i(\underline{s}, \bar{s})$ . Hence, the low-quality firm earns higher profits when it introduces a new product in the high-quality area.

## 4.2 Intermediate-Quality Innovation by the Low-Quality Firm

The results for the product market competition (stage 3) are shown in Appendix 3. We proceed investigating the innovator's choice to keep or withdraw the existing product (stage 2).

### 4.2.1 Keep or Withdraw - Stage 2

The low-quality firm's decision to withdraw the existing product from the market is given by Proposition 1. Therefore, two products are offered in the market: the low-quality firm's new product with quality  $s_1$  and the high-quality firm's existing product with quality  $\bar{s}$ . The results are shown in Appendix 1, setting  $s_1 = \underline{s}$ .

### 4.2.2 Quality Choice - Stage 1

In a next step, we investigate the low-quality firm's incentive to introduce a new product in the intermediate-quality area. By definition of the low-quality firm's convex profit function (stage 3) and the concave R&D cost function, it follows that it is always profitable to increase quality, up to where the strategic and the demand effect are balancing out, here  $s_1 = \frac{4}{7}\bar{s}$ .

## 4.3 High-Quality Innovation (Case *a*) versus Intermediate-Quality Innovation (Case *b*) by the Low-Quality Firm

Next, we analyze under which conditions the low-quality firm introduces a new product in the high-quality area (case *a*), or in the intermediate-quality area (case *b*). The low-quality firm prefers introducing a new product in the high-quality area, when

$$\begin{aligned} \tilde{\Pi}_1(\cdot) - \Pi_1(\cdot) &= \tilde{\pi}_1(\bar{s}, \tilde{s}_1(\gamma)) - F(\underline{s}, \tilde{s}_1(\gamma), \gamma) \\ &\quad - [\pi_1(s_1(\gamma), \bar{s}) - F(\underline{s}, s_1(\gamma), \gamma)] > 0, \end{aligned} \quad (14)$$

with  $\tilde{s}_1 > \bar{s} > s_1$ . Differentiating equation (14) with respect to  $\gamma$ , applying the envelope theorem, and rearranging, gives us

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<sup>11</sup>The profits (stage 3) are shown in Appendix 1, equation (17).

$$\begin{aligned} \frac{d \left[ \tilde{\Pi}_1(\cdot) - \Pi_1(\cdot) \right]}{d\gamma} &= \frac{\partial F(\underline{s}, s_1(\gamma), \gamma)}{\partial \gamma} - \frac{\partial F(\underline{s}, \tilde{s}_1(\gamma), \gamma)}{\partial \gamma} \\ &= (s_1 - \underline{s})^2 - (\tilde{s}_1 - \underline{s})^2 < 0. \end{aligned} \quad (15)$$

As we see in equation (15), the low-quality firm's incentive to offer a new product in the high-quality area declines as the R&D production costs for quality increase. Setting  $\gamma = 0$  and inserting into equation (14),

$$\left[ \tilde{\Pi}_1(\cdot) - \Pi_1(\cdot) \right] \Big|_{\gamma=0} = \frac{4\tilde{s}_1^2(\tilde{s}_1 - \bar{s})}{(4\tilde{s}_1 - \bar{s})^2} - \frac{s_1\bar{s}(\bar{s} - s_1)}{(4\bar{s} - s_1)^2} > 0. \quad (16)$$

From equation (15) and (16) follows that an unique  $\gamma = \gamma' > 0$  exists, for which  $\left[ \tilde{\Pi}_1(\cdot) - \Pi_1(\cdot) \right] \Big|_{\gamma=\gamma'} = 0$  applies. We can summarize the different cases when the low-quality firm introduces a new product (case *a* and *b*) as stated in the following proposition.

**Proposition 2** *The low quality firm introduces a new product:*

- a) in the intermediate quality area, when the production costs for quality are high ( $\gamma > \gamma'$ ) and the degree of product differentiation is sufficiently large*
- b) in the high quality area, when the production costs for quality are small ( $\gamma < \gamma'$ ).*

*The low quality firm always withdraws the existing product after introducing a new product.*

In the next chapter, we turn to the case when the high-quality firm may introduce a new product into the market.

## 5 New Product Introduction by the High-Quality Firm

As shown in Proposition 1, the high-quality firm withdraws its existing product with lower quality from the market. Therefore, it will not introduce a new product with lower quality as shown in case *e*. Case *f* can be ruled out, similar to case *a* adjusted for corresponding quality order. We are left to analyze case *d*, in which the high-quality firm may introduce a new product in the high-quality area. The results for the product market competition (stage 3) are shown in Appendix 4.

### 5.1 Keep or Withdraw - Stage 2

The high-quality firm is better off withdrawing its existing product from the market (see Proposition 1). Two products with qualities  $s_2 > \underline{s}$  are offered in the market and the same results as in Appendix 1, setting  $s_2 = \bar{s}$ , apply.

## 5.2 Quality Choice - Stage 1

The high-quality firm always has an incentive to introduce a new product in the high-quality area, explained by the properties of the profit and R&D cost function, as mentioned above.

**Proposition 3** *The high quality firm always has an incentive to introduce a new product in the high quality area and withdraws the existing product from the market.*

Taking all innovation cases together, we can derive three types of equilibria depending on who the innovator is, and on the R&D production costs for quality.

- 1) The low-quality firm introduces a new product in the high-quality area (case *a*) and withdraws the existing product from the market, if the R&D production costs for quality are small ( $\gamma < \gamma'$ ).
- 2) The low-quality introduces a new product in the intermediate-quality area (case *b*) and withdraws the existing product from the market if the R&D production costs for quality are high ( $\gamma > \gamma'$ ) and the degree of product differentiation is large. If the degree of product differentiation is only small, it may not introduce a new product into the market.
- 3) The high-quality firm always introduces a new product in the high-quality area (case *d*) and withdraws the existing product from the market.

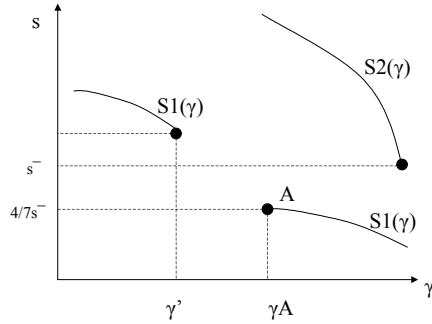
As shown in the previous analysis, all different innovation cases are characterized by two characteristics: the innovator introduces a new product with higher quality than its existing product quality, and the innovator withdraws the existing product from the market.

## 6 Innovation Policy

In the following, we illustrate the consequences of an R&D subsidy provided to firms in order to stimulate their incentives to introduce new products. As the impact of an R&D subsidy depends on firms' decisions regarding existing products that determine their degree of competitiveness, an R&D subsidy may have a very different impact on firms' decisions regarding price and quality. We consider an R&D subsidy ( $s > 0$ ) that lowers the R&D production costs for quality, e.g., that lowers the R&D cost parameter  $\gamma - s$ . Hence, the R&D costs for producing quality becomes less expensive. We will first discuss the impact of an R&D subsidy provided to a low-quality firm.

**R&D subsidy provided to the low-quality firm:** If the R&D subsidy is small, such that  $\gamma - s > \gamma'$  (see Figure 2), and the degree of product differentiation is large, the low-quality firm will introduce a new product in the intermediate-quality range and withdraw the existing product, as analyzed in case *b*. Consequently, the new product becomes a closer substitute for the high-quality firm's product and prices will decline in response to the strategic effect. If the degree of product differentiation is low (e.g., the low-quality firm offers a product with quality  $\underline{s} = \frac{4}{7}\bar{s}$  as indicated by point A in Figure 2) the R&D subsidy may not trigger further innovation by the low-quality firm, so as to avoid tougher price competition.

If the R&D subsidy is sufficiently large ( $\gamma - s < \gamma'$ ), the low-quality firm leapfrogs over the high-quality firm's product and introduces a new product in the high-quality area while withdrawing the existing product, as analyzed in case *a*.



**Figure 2:** New Product Qualities Offered by a High- and a Low-Quality Firm

**R&D subsidy provided to the high-quality firm:** If the high-quality firm receives an R&D subsidy from a government authority, it always introduces a higher quality good and withdraws the existing product, as analyzed in case *d*. The high-quality firm introduces an even higher product quality into the market compared to the low-quality firm, as the high-quality firm makes higher profits resulting in

higher expenditures in R&D; this characteristic is well known as the persistence of the high-quality advantage, see Lehmann-Grube (1997). However, the degree of product differentiation is larger than in the previous case which softens price competition and increases both product prices. Consequently, if the R&D subsidy is provided to the high-quality firm, a higher industry quality will be offered at the expense of *all* consumers paying higher prices for the products, even those who were buying the low-quality product.

## 7 Conclusion

This paper provides insight into firms' incentives to introduce a new product quality and optimal provision of products in vertically differentiated markets. This study investigates what consequences an R&D subsidy may have on new product quality and prices offered in the market, when subsidies are provided to a range of firms. Since solving for product qualities in closed form is not tractable, we implicitly analyze the effects and the conditions on R&D costs impacting an innovator's decisions to introduce a new product.

This study finds that innovators always introduce a new product of higher quality than their existing product, depending on the R&D production costs for quality. Moreover, innovators withdraw their existing products from the market in order to soften price competition and to avoid cannibalizing demand for their new product. We show that the strategic and cannibalization effects are so strong, that no room is left for discrimination among consumers; instead, these firms higher profits despite offering a smaller variety of goods. Hence, the gap between the products is not limited towards intermediate qualities or rivals' products as found in horizontal models, but also holds among its own products, see Champsaur and Rochet (1990). Moreover, we can conclude that the distribution of quality preferences plays an important role in determining firms' decisions regarding proliferating their product space. In contrast to vertical differentiation models based on a bimodal distribution of preferences for quality, our model supports firms' decision to withdraw existing products from the market.

This fundamental result is important in order to evaluate the impact of R&D subsidies provided by a government agency. This study shows that an R&D subsidy provided to a high-quality firm results in a higher industry quality offered at a higher adjusted price, than if the same subsidy had been provided to a low-quality firm. This result is consistent with the leadership persistence of a high-quality firm (Lehmann-Grube, 1997). Since the high-quality provider withdraws the existing product from the market in order to reduce price competition, the price for the low-quality product increases. Therefore, the firm producing high-quality goods introduces a new product quality at the expense of *all* consumers in the market.

The impact of an R&D subsidy provided to a firm producing low-quality products is ambiguous. If the R&D subsidy is small and the degree of product differentiation is large, the low-quality firm may introduce a new product in the intermediate-quality range. However, if the degree of product differentiation is small, the low-



quality firm may not introduce a new product into the market in order to avoid producing substitutes closer to the high-quality firm's product. If the R&D subsidy is large, the low-quality firm may leapfrog over the high-quality firm's product, but the low-quality firm offers a lower quality at lower quality adjusted prices instead of providing the R&D subsidy to the high-quality firm, since the disparity between the product qualities is smaller in this scenario.

## 8 APPENDIX

### Appendix 1: The Outset

The outset is based on the model by Choi and Shin (1992) which is a modification of Shaked and Sutton (1982) where we use the version of Tirole (1992). The model is a noncooperative two-stage game where two firms ( $i = 1, 2$ ) simultaneously choose their qualities in the first stage and given their qualities, they compete in the second stage with prices in the product market.

Product qualities  $\underline{s}, \bar{s}$  with  $\underline{s} < \bar{s}$  are chosen from the following set of qualities, defined as  $[0, \tilde{s}]$  where  $\tilde{s}$  is any finite number. Firm 1 is supposed to be the low-quality provider and firm 2 is the high-quality provider. We focus on pure strategies. Consumers' preferences are described in the model section above. After deriving the corresponding demand functions, we get for the corresponding prices

$$\underline{p}(\underline{s}, \bar{s}) = \frac{\underline{s}(\bar{s} - \underline{s})}{4\bar{s} - \underline{s}}, \text{ and } \bar{p}(\underline{s}, \bar{s}) = \frac{2\bar{s}(\bar{s} - \underline{s})}{4\bar{s} - \underline{s}}.$$

For demand, we get

$$\underline{D}(\underline{s}, \bar{s}) = \frac{\bar{s}}{4\bar{s} - \underline{s}}, \text{ and } \bar{D}(\underline{s}, \bar{s}) = \frac{2\bar{s}}{4\bar{s} - \underline{s}}.$$

Profits are

$$\underline{\pi}(\underline{s}, \bar{s}) = \frac{\underline{s}\bar{s}(\bar{s} - \underline{s})}{(4\bar{s} - \underline{s})^2}, \text{ and } \bar{\pi}(\underline{s}, \bar{s}) = \frac{4\bar{s}^2(\bar{s} - \underline{s})}{(4\bar{s} - \underline{s})^2}. \quad (17)$$

Reduced-form profit functions are continuous and differentiable, given by

$$\frac{\partial \underline{\pi}(\underline{s}, \bar{s})}{\partial \underline{s}} = \frac{\bar{s}^2(4\bar{s} - 7\underline{s})}{(4\bar{s} - \underline{s})^3} \underset{<}{\geq} 0 \text{ for } \underline{s} \underset{>}{\leq} \frac{4}{7}\bar{s}, \text{ and} \quad (18)$$

$$\frac{\partial \bar{\pi}(\underline{s}, \bar{s})}{\partial \bar{s}} = \frac{4\bar{s}(4\bar{s}^2 + 2\underline{s}^2 - 3\underline{s}\bar{s})}{(4\bar{s} - \underline{s})^3} > 0. \quad (19)$$

$$\frac{\partial \underline{\pi}(\underline{s}, \bar{s})}{\partial \bar{s}} = \frac{\underline{s}^2(\underline{s} + 2\bar{s})}{(4\bar{s} - \underline{s})^3} > 0, \text{ and} \quad (20)$$

$$\frac{\partial \bar{\pi}(\underline{s}, \bar{s})}{\partial \underline{s}} = \frac{4\bar{s}^2(\underline{s} + 2\bar{s})}{(\underline{s} - 4\bar{s})^3} < 0. \quad (21)$$

$$\frac{\partial^2 \underline{\pi}(\underline{s}, \bar{s})}{\partial \underline{s}^2} < 0, \text{ and } \frac{\partial^2 \bar{\pi}(\underline{s}, \bar{s})}{\partial \bar{s}^2} < 0. \quad (22)$$

From equation (18) we see that the low-quality firm's profits first increase in quality since more consumers buy the new product (*demand effect*). But the closer the product quality is moved towards the competitor's product the higher is the price competition (*strategic*

*effect*) which decreases the low-quality firm's profits. When both product qualities are identical Bertrand competition drives firms' profits to zero. The low-quality provider's optimal distance to the high-quality product is given by the point where the *demand effect* and the *strategic effect* are balancing each other. The high-quality firm increases profits by offering a higher product quality. We get the result of 'maximal product differentiation' where in equilibrium firms maximally differentiate their products. The low-quality firm offers the lowest feasible product quality and the high-quality firm offers the highest feasible product quality.

## Appendix 2: Two Adjacent Products offered in the Market

In order to proof the existence of Proposition 1, we consider the following two scenarios: the low-quality firm offers two adjacent products in the market (cases *b* and *c*), and the high-quality firm offers two adjacent products in the market (cases *d* and *e*).

Two adjacent products offered by the low-quality firm: Let us begin with case *b*, in which the low-quality firm offers two adjacent products with the lowest quality,  $\underline{s} < s_1 < \bar{s}$  at prices  $\underline{p} < p_1 < \bar{p}$ . The low-quality firm's decision to withdraw or keep its product with lowest quality  $\underline{s}$ , depends on the difference in firms' profits, respectively, given by

$$\pi_1^w = \left[ \frac{(\bar{p} - p_1)}{(\bar{s} - s_1)} - \frac{p_1}{s_1} \right] p_1$$

and

$$\pi_1^k = \left[ \frac{(\bar{p} - p_1)}{(\bar{s} - s_1)} - \frac{(p_1 - \underline{p})}{(s_1 - \underline{s})} \right] p_1 + \left[ \frac{(p_1 - \underline{p})}{(s_1 - \underline{s})} - \frac{\underline{p}}{\underline{s}} \right] \underline{p}.$$

The difference is,

$$\pi_1^w - \pi_1^k = \frac{(s_1 \underline{p} - \underline{s} p_1)^2}{s_1 \underline{s} (s_1 - \underline{s})} > 0. \quad (23)$$

As shown in equation (23), the low-quality firm earns higher profits when it withdraws its product with lower quality  $\underline{s}$ . Moreover, we see that the rival's offer does not have an impact on the difference of low-quality firm's profits. Note, that this result holds even under the assumption that the same prices are charged under both regimes, and we can therefore abstract from any strategic effects. The low-quality firm has a dominant strategy to withdraw the product with lowest quality.

This result is redundant to case *c*, in which the low-quality firm will not introduce a new product with quality  $s_1$  in the low-quality area. Therefore, we can generalize this result as follows:

**Lemma 1** *A firm offering the lowest two product qualities in the market, will always withdraw the product with lowest quality from the market.*

Two adjacent products offered by the high-quality firm: Let us now turn to the innovation cases *d* and *e*, in which the high-quality firm offers the highest two adjacent product qualities. We begin with case *d*, in which the high-quality firm offers the two highest

adjacent products with quality  $s_2 > \bar{s}$  at prices  $p_2 > \bar{p}$ . The high-quality firm's difference in profits when withdrawing or keeping its low-quality product, is given by,

$$\begin{aligned} \pi_2^w - \pi_2^k &= \frac{[(\bar{s} - \underline{s}) p_2 - (s_2 - \underline{s}) \bar{p}] [(s_2 - \bar{s}) \underline{p} + (\bar{s} - \underline{s}) p_2 - (s_2 - \underline{s}) \bar{p}]}{(s_2 - \underline{s}) (\bar{s} - \underline{s})} \\ &> 0. \end{aligned} \tag{24}$$

As we see in equation (24), the high-quality firm earns higher profits when withdrawing its lowest product quality  $\bar{s}$ . Since this result also holds for case  $e$ , we obtain the following result:

**Lemma 2** *A firm offering the highest two product qualities in the market will always withdraw the lower quality product from the market.*

Taking both cases together, in which the low or the high-quality firm offers two adjacent products, gives the result as stated in Proposition 1. We can explicitly rule out the innovation cases  $c$ ,  $e$ , and  $f$ , in which the firm wants to introduce a new product with lower quality.

### Appendix 3: Intermediate-Quality Innovation by the Low-Quality Firm

In case  $b$ , the low-quality firm introduces a new product in the intermediate-quality area  $s_1 < \bar{s}$ . Firms' profit functions are given by

$$\begin{aligned} \pi_1^k(\underline{p}, \underline{D}, p_1, D_1) &= \underline{p}\underline{D}(\cdot) + p_1 D_1(\cdot), \text{ and} \\ \bar{\pi}(\bar{p}, \bar{D}) &= \bar{p}\bar{D}(\cdot). \end{aligned}$$

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 its existing product price is given by

$$\frac{\partial \pi_1^k(\underline{p}, \underline{D}, p_1, D_1)}{\partial \underline{p}} \equiv 0 \implies \underline{p}(p_1) = \frac{p_1 \underline{s}}{s_1}$$

and with respect to its new product price, internalizing the price effect of its new product price on its existing product price is given by

$$\frac{\partial \pi_1^k(\underline{p}, \underline{D}, p_1, D_1)}{\partial p_1} \equiv 0 \implies p_1(\bar{p}) = \frac{\bar{p} s_1}{2\bar{s}}.$$

The first order condition for the high-quality firm, is

$$\frac{\partial \bar{\pi}(\bar{p}, \bar{D})}{\partial \bar{p}} \equiv 0 \implies \bar{p}(p_1) = \frac{p_1 - s_1 + \bar{s}}{2}.$$

The reaction functions are strictly monotone. Solving the first order conditions gives the corresponding prices

$$\underline{p}(\underline{s}, s_1, \bar{s}) = \frac{\underline{s}(\bar{s} - s_1)}{4\bar{s} - s_1}, \quad p_1(s_1, \bar{s}) = \frac{s_1(\bar{s} - s_1)}{4\bar{s} - s_1},$$

$$\text{and } \bar{p}(s_1, \bar{s}) = \frac{2\bar{s}(\bar{s} - s_1)}{4\bar{s} - s_1}.$$

The demand is

$$\underline{D}(\cdot) = 0, \quad D_1(s_1, \bar{s}) = \frac{\bar{s}}{4\bar{s} - s_1}, \quad \text{and } \bar{D} = \frac{2\bar{s}}{4\bar{s} - s_1}. \quad (25)$$

Firms' profits are as follows

$$\pi_1^k(\cdot) = 0, \quad \pi_1(s_1, \bar{s}) = \frac{s_1\bar{s}(\bar{s} - s_1)}{(4\bar{s} - s_1)^2}, \quad \text{and} \quad (26)$$

$$\bar{\pi}(s_1, \bar{s}) = \frac{4\bar{s}^2(\bar{s} - s_1)}{(4\bar{s} - s_1)^2}. \quad (27)$$

#### Appendix 4: High-Quality Innovation by the High-Quality Firm

In case  $d$ , the high-quality firm introduces a new product in the high-quality area  $s_2 > \bar{s}$ . Firms' profit functions are given by

$$\underline{\pi}(\underline{p}, \underline{D}) = \underline{p}\underline{D}(\cdot), \quad \text{and}$$

$$\bar{\pi}_2^k(\bar{p}, \bar{D}, p_2, D_2) = \bar{p}\bar{D}(\cdot) + p_2 D_2(\cdot).$$

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

$$\frac{\partial \underline{\pi}(\underline{p}, \underline{D})}{\partial \underline{p}} \equiv 0 \implies \underline{p}(\bar{p}) = \frac{\bar{p}\bar{s}}{2\bar{s}}.$$

The first order condition for the high-quality firm with respect to the price of the high-quality product, is as follows

$$\frac{\partial \bar{\pi}_2^k(\bar{p}, \bar{D}, p_2, D_2)}{\partial p_2} \equiv 0 \implies p_2(\bar{p}) = \frac{2\bar{p} - \bar{s} + s_2}{2},$$

and with respect to its existing product price,

$$\frac{\partial \bar{\pi}_2^k(\bar{p}, \bar{D}, p_2, \bar{p}, D_2)}{\partial \bar{p}} \equiv 0 \implies \bar{p}(\underline{p}) = \frac{\underline{p} - \underline{s} + \bar{s}}{2}.$$

The reaction functions are strictly monotone. Solving the first order conditions yields the corresponding prices

$$\underline{p}(\underline{s}, \bar{s}) = \frac{\underline{s}(\bar{s} - \underline{s})}{4\bar{s} - \underline{s}}, \quad \bar{p}(\underline{s}, \bar{s}) = \frac{2\bar{s}(\bar{s} - \underline{s})}{4\bar{s} - \underline{s}}, \quad \text{and}$$

$$p_2(\underline{s}, \bar{s}, s_2) = \frac{4\bar{s}s_2 - \underline{s}(s_2 + 3\bar{s})}{2(4\bar{s} - \underline{s})}.$$

Substituting these gives us the equivalent demand

$$\underline{D}(\underline{s}, \bar{s}) = \frac{\bar{s}}{4\bar{s} - \underline{s}}, \quad \bar{D}(\underline{s}, \bar{s}) = \frac{\underline{s}}{2(4\bar{s} - \underline{s})}, \quad \text{and} \quad D_2 = \frac{1}{2}.$$

Similarly, firms' profits in the product market are

$$\underline{\pi}(\underline{s}, \bar{s}) = \frac{\underline{s}\bar{s}(\bar{s} - \underline{s})}{(4\bar{s} - \underline{s})^2}, \quad \text{and}$$

$$\pi_2^k(\underline{s}, \bar{s}, s_2) = \frac{\underline{s}\bar{s}(\bar{s} - \underline{s})}{(4\bar{s} - \underline{s})^2} + \frac{4\bar{s}s_2 - \underline{s}(3\bar{s} + s_2)}{4(4\bar{s} - \underline{s})}. \quad (28)$$

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