The Effect of Quality Decisions on Competitive Strategy

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ABSTRACT

This dissertation analyzes how quality decisions are given and their respective effects on strategic marketing variables such as pricing and advertising decisions. I study quality decisions in three unique settings in three essays.

The first essay studies the strategic interaction between firms producing strictly complementary products. I show that both value-capture and value-creation problems occur when such products are developed and sold by separate firms. Separate firms charge higher prices and choose lower levels of quality. A royalty structure may mitigate the value-capture problem to some extent at the expense of a more serious value-creation problem. Somewhat surprisingly, the result can change with competition. Specifically, when there is vertically differentiated competition in one of the product markets, the value-creation problem is reduced, opening the door to the possibility of a win-win-win-win situation in which all firms and consumers are better off.

The second essay studies the strategic decisions of vertically differentiated firms that promote their products online utilizing display or search engine advertising. In such a setting firms' decisions may lead to informational disparity in the marketplace that softens price competition. Specifically, a low-quality firm may choose not to run a display advertising campaign, even when administering such a campaign is costless,

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if the degree of vertical differentiation between the goods is small. Moreover, as the degree of advertising effectiveness goes up the low-quality firm can be better off (despite not advertising). In the case of search engine advertising, the high-quality firm acquires the top sponsored link over a large range of the parameter space, as the value of advertising is typically greater for it. However, if advertising effectiveness is moderate and vertical differentiation is small, the low-quality firm will win the auction for the top link.

The third essay explores quality decisions of media firms that operate in two-sided markets: they sell content to readers and sell advertising space to advertisers. I find that while competition often drives firms to overinvest in quality and charge lower prices relative to a monopolist media firm, there exist conditions whereby competition results in lower quality selected and higher prices.

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1. COMPLEMENTARY GOODS: CREATING, CAPTURING, AND COMPETING FOR VALUE

1.1 *Introduction*

In a number of prominent markets, consumers have to purchase and use multiple products simultaneously to derive positive utility. The goods involved in consumption are, therefore, highly complementary and value is derived from their joint consumption. The complex technology and know-how involved in developing each of the products can require specialized organizational skills. Thus, separate firms often produce the individual goods and rely on each other to produce the complementary product.

There are several noteworthy examples of such an interaction. In the emerging category of smart phones, one firm typically designs and produces the device and operating platform while other firms create applications for it (as is the case with the iPhone). The video game industry is another example that embodies characteristics of strictly complementary goods: a video game such as Guitar Hero has no use without the console and a gaming platform has no use without games.[1] In the case of computers, one firm produces the central processor while another produces the oper-

[1] We acknowledge that in hardware-software settings other factors can be relevant, for example, network effects and the ability to use one of the products without the other. We discuss the former issue in Section 1.2 (Related Literature) and the latter in Section 1.6 in connection with an extension we studied.

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ating system; with electric instruments, one firm typically focuses on the instrument itself (say the synthesizer) while another firm focuses on the amplifying equipment.

Because of the joint consumption characteristic, there is, in many instances, a quality interdependence among the goods produced: the utility that consumers derive from one product depends not only on that product's quality but also on the quality of the complementary good. For example, a more advanced operating system delivers better performance only if the microprocessor hardware is capable of handling the operating system's increase in code complexity. But improving quality requires costly upfront research and development (R&D) investments that can complicate the quality decision, as each producer relies on its counterpart's efforts. Indeed, given the need for the complementary products to work together, they are typically designed sequentially, with the second product developed according to specifications set by the first one. For instance, decisions regarding hardware architecture are usually made before software code is written.

The fact that consumers need to purchase both goods has strategic implications for the firms involved. Specifically, if we view the revenue pie as consisting of the total amount consumers spend on the two complementary products, the question arises as to how this pie is split. With video games, for example, total industry revenue in the United States reached $24.3 billion in 2011 (NPD Group, 2012) from the sale of consoles, games, and accessories—far surpassing movie box office revenue. The desire to capture a greater share of this soaring revenue stream generates a pricing tension between console makers and game publishers. Each would like to price higher but an increase by both could make the total price the consumer pays too high. Complicating matters is that there may be competition in one of the markets, such as when more than one hardware platform can run the software application or game

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title, resulting in pressure to lower prices to appeal to consumers.[2]

Given these challenges to capturing as much value as possible, utilizing royalty fees is a prominent feature in many complementary product markets. Video console producers charge game publishers a royalty fee for the right to publish games for their consoles, and a similar arrangement exists for applications sold separately for smart phones. As one might expect, the firm that levies the royalty fee attempts to appropriate a portion of the value otherwise captured by the complementary producer. But whether the firm charging such a fee is vastly better off depends on how the royalty arrangement impacts firms' actions, particularly in terms of the incentives to create value through their choice of quality levels.

In this essay, we study the strategic interaction among firms producing highly complementary products and focus on the following research questions:

- How do firms make pricing and quality investment decisions in light of the joint consumption of their products?
- How does a royalty structure affect the interaction between firms in this context? Does it lead to a larger or smaller incentive to invest in quality?
- What impact does competition have on each of the complementary firms? Should we necessarily expect the payoff of a firm facing a direct competitor to decrease?

To answer these questions, we construct a stylized model in which two firms develop complementary products and one firm must design its product (product A, the "hardware") before the complementary product (product B, the "software") can be designed. The firms incur a greater cost when they develop a higher-quality

[2] For example both Sony's PlayStation 3 and Microsoft's Xbox 360, two competing video game consoles, run Guitar Hero.

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product and consumers derive utility only if both products are consumed together. The analysis reveals that, for given quality levels, the joint consumption but separate production and sale of complementary goods yields an incentive for firms to price higher as compared to the benchmark case of an integrated firm that produces and sells both goods. This is due to the fact that the prices of complementary products sold by separate firms form strategic substitutes, i.e., if one firm tries to cut its price to stimulate demand, the other firm has an incentive to increase its price.[3] Because each firm wants to free-ride on the other firms' lower price, the result is that both prices are higher relative to the integrated case for given quality levels. Higher prices by both producers leads to limited demand—in other words, firms are not capturing as much value as they possibly can.

We further find that each producer wants to shirk on quality and let the other producer carry most of the quality-provision burden. This is because the qualities of complementary products form strategic complements: if one firm decreases quality to save on development costs, the other firm's best response is to decrease the quality of its product. Consequently, there is a value creation problem. In fact, and in contrast to the extant literature, the resulting product qualities are so low that the firms end up charging prices that are well below those charged by an integrated firm. Furthermore, the second mover (firm B) shirks more on quality investments than the first mover (firm A), thereby creating a quality gap between the two products. In some sense, the selection of greater quality by the first-mover generates a positive externality on the B firm, allowing it to select a lower quality level.

We show that the ability of one firm to mandate a royalty fee from the complementor firm has advantages and disadvantages. It enables the firm receiving the

[3] Our use of the terms "strategic substitutes" and "complements" follows Bulow et al. (1985).

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royalty payments to capture a larger slice of the revenue pie, but shrinks the size of that pie. Specifically, a royalty arrangement exacerbates the value-creation problem because it causes the second mover to invest even less in product development, thus leading to even lower quality for the composite complement pair.

Interestingly, we find that the presence of a direct competitor can mitigate the value-creation problem in a way that leaves all firms and consumers better off. Specifically, when the first mover A firm faces competition from a vertically differentiated product, prices in that market tend to plummet. But because consumers only care about the total price they pay, this allows the B firm to charge relatively high prices and make considerable profits. This, in turn, provides the B firm a strong incentive to select a higher quality level. The result is a greater overall level of quality for the complement pair and an increase in the size of the revenue pie. For the first mover that faces competition, the benefit of getting a piece of a larger pie (through the royalty arrangement) outweighs the fact that competition causes it to have to reduce its price. Consequently, this leads to a win-win-win-win situation in which all the firms in the market and consumers are better off. Notably, the role of competition in yielding this outcome cannot be overstated. In particular, if the A firm were given the option to introduce a lower-quality product variant, it could not credibly commit to the same pricing levels and the B firm would not invest sufficiently in quality. The A firm is thus strictly better off when a competitor introduces the lower-quality product.

The strategic interaction between firms that produce substitute products has been well researched (Desai, 2001; Schmidt-Mohr and Villas-Boas, 2008). The incentives of such firms are naturally conflicting. One could intuitively suggest that the incentives of firms that produce strictly complementary products should be more closely aligned. Our work shows that this is not necessarily the case. Producers of strict

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complements have conflicting incentives in their efforts to create and capture value, and prescriptions for dealing with these conflicts may be counterintuitive. In particular, we show that when attempting to mitigate the value-creation problem for complementary products, firms should sometimes welcome and even encourage direct competitors to enter the market.

The rest of the essay is organized as follows. In the next section we relate our work to the extant literature. Section 1.3 presents the model set-up. Section 1.4 first solves the benchmark case of an integrated firm (a single firm that produces both complementary products) and then analyzes the strategic interaction between two non-integrated producers with and without a royalty-fee structure. Section 1.5 introduces competition in the first mover's market. Section 1.6 discusses several model extensions and Section 1.7 concludes and provides managerial implications. All proofs have been relegated to the Appendix.

1.2 Related Literature

One of the first analyses of the interaction between producers of complementary products was done by Cournot (1838). He modeled two firms that produce complementary goods (zinc and copper) that are in turn combined to make a composite product (brass). He showed that both firms share profits equally regardless of differences in marginal costs. The issue of how profits are divided between complement producers has received new interest recently with a stream of literature looking at "one-way complements." With one-way complements, one of the products (A) has value for consumers by itself while the other (B) is useless without the first one. That makes one of the complementary products "essential" and its value can be enhanced by the "nonessential" product. Cheng and Nahm (2007), for example, examined how

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prices are influenced by the value of the essential good (A) relative to the value of the bundle (AB). Chen and Nalebuff (2006) explored how the firm producing the essential product can appropriate some of the value from the nonessential B product by imposing royalty fees or by introducing its own B product. However, in all of these papers, product qualities are exogenous. By contrast, we consider the case in which quality levels are endogenous and introduce the possibility of competition in the A product market. Furthermore, to rule out the trivial explanation that asymmetric quality investments occur because only one of the goods is essential, each good in our analysis has no value without the other (two-way complementarity).

As in our model, Economides (1999) examined the quality decisions of two-way-complement firms. In his model, the composite product's quality is equal to the minimum quality of the two products. Yet as he notes, this approach is appropriate for a long-distance telecom service, which requires the use of a long distance line as well as local lines at the two terminating points. In this case, the sound quality will be the minimum of the qualities of the different services used. In our model, the qualities of the products are supermodular: the impact on the composite product's quality from an incremental increase in the quality of one component depends on the absolute quality level of the other component. This approach better suits the hardware-software complementary product pairs that we have in mind.

Farrell and Katz (2000) and Casadesus-Masanell et al. (2007) considered competition with strict complementarities, but did not explore the value-creating aspect (the incentives of both producers to invest in quality). Farrell and Katz (2000) built a model in which one of the complements (A) is monopolized and the other (B) is supplied by a competitive sector. They found that the monopolist may want to supply its own version of B and destroy the incentives to innovate in the competitive B sector.

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However, the quality of the monopolized complementary product is fixed. We, on the other hand, look at the incentives to innovate in both markets. Casadesus-Masanell et al. (2007) showed that when there are two firms in the A market and a single B firm, the lower-quality A firm cannot have positive sales.[4] We show that allowing the B firm to discriminate in prices and enabling royalty mechanisms can result in all three firms having positive demand at positive prices. Importantly, we characterize conditions under which the firms make greater profits in the presence of competition than in its absence—effectively leading to a win-win-win outcome (because consumers are also better off in this case we find a fourth "win").

Given that positive externalities arise in our context (for example, if one firm improves its quality there is an indirect impact on the complementary product's demand), there is some connection to the network effects literature. Economides (1996) distinguishes between two types of network externalities: direct (when the utility of a consumer increases as an explicit function of the number of other users) and indirect (when the utility of the consumer rises as a result of the actions of other industry players that benefit from more users of the firm's product). Our model has an indirect network externalities flavor in the spirit of Chou and Shy (1989). Economides and Viard (2010) establish an equivalence between a model that has a base (essential) and a complementary (non-essential) good and a model that has a base good and reduced form network externalities. In this framework, they consider quality improvement decisions of complementary products. Our analysis differs in that we investigate the interplay between royalty arrangements and competition and in that complementarity in our model goes both ways.

[4] They produce an equilibrium in which the low-quality firm has positive sales under an assumption that the software producer's follow-on future sales to the installed base are greater than total marginal costs incurred.

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That said, we wish to acknowledge that in some of our motivating examples there are aspects of strict complementarity as well as direct network effects. For example, with a video game like Guitar Hero, there are multiple consumption interdependencies: consumers need a compatible console and the title with its accessory to derive positive utility in the music playing genre of games (the complementarity aspect), and the more people own both this utility may increase because of the ability to play with others (the direct network effect aspect). In this essay we focus on the first issue. Other papers have examined the direct network externality aspects of such industries (without getting into complementarities among players and investments in quality); see, for example, Dhebar and Oren (1985), Sun, Xie and Cao (2004), and Chien and Chu (2008).

Lastly, our essay is also loosely related to the literature on product bundling (McAfee et al., 1989; Venkatesh and Kamakura, 2003) since, in the integrated case (which we solve as a benchmark), a single firm can sell the complementary products as a bundle. Our work is different because we examine perfect complements and hence the value (reservation price) is zero for each product by itself. By contrast, the bundling literature typically deals with goods that individually have value when consumed separately. Furthermore, we focus on the strategic case in which the products are sold by separate profit-maximizing firms and on potential monetary arrangements between them (royalty fees).

1.3 Model Setup

1.3.1 Products

Consider a market with two strictly complementary products, A and B. Consumers derive utility only if they use both products together as a composite good

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that we denote as AB. This utility is governed by the quality of the composite good, which we model as a multiplication of the quality levels of each component; thus capturing the notion of strict complementarity. More formally, the quality of the composite product, q, is given by $q = \alpha\beta$ where α is the quality of product A and β is the quality of product B.[5]

With this specification we have, $\frac{\partial q}{\partial \alpha} = \beta$ and $\frac{\partial q}{\partial \beta} = \alpha$, which implies that the impact on consumer utility of increasing one's own product quality level is greater when the complementing product is of higher quality. For example, a computer with a 64-bit processor is more powerful when paired with an x64 edition of the operating system because that version can better use the capabilities of the advanced processor.

1.3.2 *Consumers*

We assume that the market is composed of a unit mass of consumers who have the same preference ordering of (potential) composite products that are offered at the same price. All consumers prefer higher quality over lower quality, but they are heterogeneous in their willingness to pay for quality. The marginal valuation of quality, θ, is distributed uniformly on $[0, 1]$. The utility a consumer derives from buying product A and product B with quality levels α and β at prices p_A and p_B is equal to $U = \theta\alpha\beta - p_A - p_B$. A consumer buys a product pair if her valuation is higher than the sum of the prices, p_A and p_B (i.e., $U_i \geqslant 0$). Thus, the indifferent consumer has the taste parameter $\widehat{\theta} = \frac{p_A + p_B}{\alpha\beta}$. All consumers of types $\theta \in \left[\widehat{\theta}, 1\right]$ will purchase both products. Demand, which is equivalent for both products in a given complementary pair, is thus equal to $1 - \widehat{\theta}$.

[5] "Quality" can be thought of simply as an attribute (or collection of attributes) that consumers always prefer more of for the same price.

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1.3.3 Cost Structure

Firms incur costs to develop products. As one would expect, it is increasingly more costly to deliver greater quality levels.[6] To capture this in the model, we assume that the cost function is increasing and convex in the quality level selected. Specifically, the cost functions for developing products with quality levels α and β are $c(\alpha) = \frac{1}{n} k_A \alpha^n$ and $c(\beta) = \frac{1}{n} k_B \beta^n$, respectively, where k_A and k_B are development cost parameters. For mathematical tractability, we solve for the case of $n = 3$.[7] Since our objective is to understand the strategic interaction between firms' quality choices, we wish to avoid outcomes that are generated merely by asymmetries in the development costs. Hence, we assume that $k_A = k_B = k$ for the analysis presented in the paper. Variable production costs are assumed to be constant and are normalized to zero.[8]

In Section 1.6 we discuss relaxing a number of the model setup characteristics.

1.4 Model Analysis

We start with the analysis of a case in which both complementary goods (A and B) are produced by a single profit-maximizing firm. This benchmark case will prove useful in understanding the strategic forces that govern firm behavior in the non-integrated case, in which separate firms produce and sell each of the complementary products.

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[6] Given our motivating examples, this is a plausible assumption. For instance, in the video game industry, upfront R&D costs are large. The latest generation of consoles required an investment on the order of billions of dollars and the budget for a typical video game ranged from $10 to $35 million (Ofek, 2008).

[7] Our analysis applies whenever the cost function is sufficiently convex (the results hold for any $n>2$).

[8] This assumption captures well the situation in industries such as software and many electronics markets, where the main cost burden comes from upfront R&D.

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1.4.1 Benchmark Case: An Integrated Producer

The integrated firm is a monopolist in the market for both products and chooses the quality levels of products A and B (α and β) and their prices. Since consumers need both products to derive value, the integrated firm effectively charges a single price, $p_I = p_A + p_B$, for the composite pair. Consumers with taste parameters that exceed $\widehat{\theta}_I = \frac{p_I}{\alpha\beta}$ buy the products and the firm solves the following problem:

$$\max_{p_I,\alpha,\beta} \pi^I = \left(1 - \widehat{\theta}_I\right) p_I - \frac{1}{3}k\alpha^3 - \frac{1}{3}k\beta^3. \tag{1.1}$$

The optimal solution of the integrated firm is given in Table 1.1 (under the heading "Integrated"). As can be seen, the profit-maximizing price is $p_I^* = \frac{\alpha\beta}{2}$. At this price, the indifferent consumer has a taste for quality $\widehat{\theta}_I = 0.5$, so half of the market is covered. The integrated firm chooses levels of quality that trade off the increased revenue generated by higher-quality products against the greater cost of development. Note from Table 1.1 that the profit-maximizing quality of the two products is the same for the integrated firm.

1.4.2 Non-integrated Producers

A single firm may not have the technology or know-how required to develop both products, and strictly complementary products developed and sold by separate firms are common in the marketplace. For instance, many firms that produce hardware (processors, game consoles, and smart phones) depend on other firms to develop complementary software (operating systems, game titles, and applications). Given the need for both products to work together, strictly complementary products are typically developed sequentially with development decisions about the subsequent

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product based on the specifications of the leading product. This is regularly the case for hardware-software complements. For example, Microsoft needs to know the planned architecture of a processor before it develops a compatible operating system. To capture this, we analyze a multistage game in which one firm chooses a level of quality for product A (the "hardware") before the maker of complementary product B (the "software") chooses its quality level.[9]

Table 1.1: Analytical Equilibrium Results

	Integrated	**Nonintegrated**	
		No Royalty	**With Royalty**
Quality	$\alpha_I^* = \frac{1}{2^2 k}$ $\beta_I^* = \frac{1}{2^2 k}$ $q_I^* = \frac{1}{2^4 k^2}$	$\alpha^* = \frac{1}{2^{2/3} 3^{4/3} k}$ $\beta^* = \frac{1}{2^{1/3} 3^{5/3} k}$ $q^* = \frac{1}{2 \times 3^3 k^2}$	$\alpha_R^* = \frac{5^{5/3}}{2^{13/3} 3^{4/3} k}$ $\beta_R^* = \frac{5^{4/3}}{2^{11/3} 3^{5/3} k}$ $q_R^* = \frac{5^3}{2^8 3^3 k^2}$
Price	$p_I^* = \frac{1}{2^5 k^2}$	$p_A^* = p_B^* = \frac{1}{2 \times 3^4 k^2}$	$p_A^{R*} = \frac{5^3}{2^9 3^4 k^2}$ $p_B^{R*} = \frac{5^4}{2^{10} 3^4 k^2}$
Royalty Rate	-	-	$\frac{3}{5}$
Demand	$1 - \widehat{\theta}_I = \frac{1}{2}$	$1 - \widehat{\theta} = \frac{1}{3}$	$1 - \widehat{\theta}_R = \frac{5}{12}$
Profit	$\pi_I^* = \frac{1}{2^6 3 k^2}$	$\pi_A^* = \frac{1}{2^2 3^5 k^2}$ $\pi_B^* = \frac{1}{3^6 k^2}$ $\pi_A^* + \pi_B^* = \frac{7}{2^2 3^6 k^2}$	$\pi_A^{R*} = \frac{5^5}{2^{13} 3^5 k^2}$ $\pi_B^{R*} = \frac{5^4}{2^{10} 3^6 k^2}$ $\pi_A^{R*} + \pi_B^{R*} = \frac{23 \times 5^4}{2^{13} 3^6 k^2}$
Consumer Surplus	$\frac{1}{2^7 k^2}$	$\frac{1}{2^2 3^5 k^2}$	$\frac{5^5}{2^{13} 3^5 k^2}$
Social Welfare	$\frac{5}{2^7 3 k^2}$	$\frac{5}{2 \times 3^6 k^2}$	$\frac{19 \times 5^4}{2^{12} 3^6 k^2}$

[9] The assumption of sequential development is not crucial for the paper's results. In fact, it turns out that there is a more pronounced problem of quality under-provision with simultaneous development. See Section 1.6 for details.

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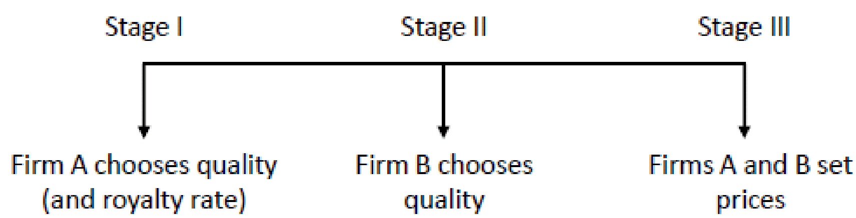

Figure 1.1: Timeline of the Game

A common practice in many industries with complements is the use of royalty fees. In the video game industry, console makers charge game publishers a royalty fee per game copy in return for permission to develop games compatible with the console (for example, Activision has to pay Microsoft a royalty of about 10% for each game sold). Smart phones and applications have a similar royalty structure (with about 30% in royalties). To capture this aspect of complement markets, we allow firm A, the first mover that develops and sells the A product, to impose a royalty fee on firm B, which develops and sells the B product. Consistent with industry practice, the royalty fee, r, is defined as a percentage of product B's retail price and firm B knows this rate when finalizing its quality decision. The general timeline of the game is shown in Figure 1.1.

We next analyze the case of non-integrated complement firms. We divide the analysis into two parts: first, we consider the case of non-integrated complements that lack a royalty fee structure, and then we look at how the addition of royalty fees affects the results.

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Case of No Royalty Fees

When there are no royalty fees, the sequence of moves is as follows. In the first stage firm A chooses the quality level for its product, in the second stage firm B chooses its quality level, and in the final stage firms set prices for their products simultaneously. The marginal consumer's valuation is $\widehat{\theta} = \frac{p_A + p_B}{\alpha\beta}$, and the firms' optimization problems are given by

$$\max_{\alpha, p_A} \pi_A = \left(1 - \widehat{\theta}\right) p_A - \frac{1}{3} k\alpha^3, \tag{1.2}$$

$$\max_{\beta, p_B} \pi_B = \left(1 - \widehat{\theta}\right) p_B - \frac{1}{3} k\beta^3. \tag{1.3}$$

We solve the model by working backward from the final pricing stage. From the solution to the Non-integrated (no royalty) case in Table 1.1, we see that firms' equilibrium prices are $p_A^* = p_B^* = \frac{\alpha\beta}{3}$. For given quality levels, these prices are clearly higher than what the integrated firm would charge as $p_A^* + p_B^* = \frac{2\alpha\beta}{3} > p_I^* = \frac{\alpha\beta}{2}$. This results in lower demand for the products at given quality levels and reflects the *value-capture* problem of non-integrated firms that produce complementary products. This problem occurs because when one firm cuts its price, this has a positive externality on its rival's pricing. More specifically, if one of the firms decreases its price, the other firm benefits from the resulting increase in demand as well, and its best response is to increase price. Formally, prices of complementary products form strategic substitutes for given quality levels. Thus, even if both firms would be better off with lower prices, neither wants to deviate unilaterally from the high price they charge.

Taking the last stage pricing equilibrium into account, we can see from the solution in Table 1.1 that firms' quality selections are lower than what the integrated firm chooses (See Table 1.2 for a numerical example). In fact, the qualities are so much

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lower that the following outcome holds.

Proposition 1.1. *In equilibrium, non-integrated firms select lower levels of product quality and lower prices than those chosen by an integrated firm.*

Table 1.2: Numerical Equilibrium Results

	Integrated	**Nonintegrated**	
		No Royalty	**With Royalty**
Quality	$\alpha_I^* = 2.5$	$\alpha^* = 1.46$	$\alpha_R^* = 1.68$
	$\beta_I^* = 2.5$	$\beta^* = 1.27$	$\beta_R^* = 1.08$
	$q_I^* = 6.25$	$q^* = 1.85$	$q_R^* = 1.81$
Price	$p_I^* = 3.13$	$p_A^* = p_B^* = 0.62$	$p_A^{R*} = 0.30$
			$p_B^{R*} = 0.75$
Royalty Rate	-	-	60%
Demand	$1 - \widehat{\theta}_I = 50\%$	$1 - \widehat{\theta} = 33\%$	$1 - \widehat{\theta}_R = 42\%$
Profit		$\pi_A^* = 0.103$	$\pi_A^{R*} = 0.157$
	$\pi_I^* = 0.52$	$\pi_B^* = 1.37$	$\pi_B^{R*} = 0.084$
		$\pi_A^* + \pi_B^* = 0.240$	$\pi_A^{R*} + \pi_B^{R*} = 0.241$
Consumer Surplus	0.78	0.102	0.157
Social Welfare	1.3	0.343	0.398

The numerical values have been calculated assuming $k = 0.1$

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Proposition 1.1 reflects the severe *value-creation* problem between firms that produce complementary products. Each firm has an incentive to free-ride on the investments of its counterpart. Specifically, if firm A increases its product's quality, firm B's incentive to increase quality is not as high because it can simply increase its price to capture some of the value from firm A's quality improvement; as with a price decrease, a quality improvement thus produces a positive externality on the other firm. Such free-riding is a serious drawback because it results in firms undersupplying overall quality in equilibrium. And given that the prices firms charge are a function of the composite quality of the offerings ($\frac{\alpha^*\beta^*}{3}$), such low-levels of quality lead to lower prices. In other words, the value creation problem dominates and $p_A^* + p_B^* < p_I^*$. This result contrasts with Economides (1999), whose model yields that the total price asked by non-integrated firms is higher.[10]

We note that although both firms shirk on quality relative to the integrated case (per Proposition 1.1), they do not end up with products of the same quality in equilibrium (despite having the same development-cost parameter). The second mover has an advantage because it chooses quality after the first mover is already committed to its quality level. The ability of the second mover to choose a lower quality level translates into greater profit: the firms charge the same price and face the same demand but firm B saves on R&D investment.

In the next section, we let firm A impose a royalty fee on firm B and study how that affects the value-creation and value-capture problems between complementor firms.

[10] Economides (1999) uses $q = \min(\alpha, \beta)$ for composite quality, and thus assumes away free-riding and coordination problems in qualities between complementors.

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In the first stage of the game, let firm A set a royalty fee, $r \in [0, 1]$, that is defined as a percentage of firm B's price p_B^R (See Figure 1.1). The marginal consumer's valuation is denoted $\widehat{\theta}_R$ and the firms' profits functions are as follows:

$$\pi_A^R = \left(1 - \widehat{\theta}_R\right) \left(p_A^R + r p_B^R\right) - \frac{1}{3} k \alpha_R^3, \tag{1.4}$$

$$\pi_B^R = \left(1 - \widehat{\theta}_R\right) (1 - r)\, p_B^R - \frac{1}{3} k \beta_R^3. \tag{1.5}$$

The equilibrium solution is given in Table 1.1 (under the heading "Non-integrated, with Royalty"). The following proposition highlights the effect of royalty fees on firm behavior.

Proposition 1.2. *With royalty fees, the gap in quality selections between the firms increases while the quality of the composite good decreases. The total price for the two products decreases and market coverage increases.*

In order to understand the intuition behind Proposition 1.2 it is critical to examine how firms' incentives change under the royalty structure. From Table 1.1 we can see that compared to the non-integrated case without royalty fees, firm A increases its quality investment but firm B shirks even more; hence the quality gap between the products is exacerbated. This happens because firm A's stake in the industry's overall revenue is greater than in the case of no royalty fees, as it can now capture value both directly from the sale of its product and indirectly from the sale of product B through the royalty payments. This, in turn, increases firm A's willingness to invest in quality to attract more consumers to buy. On the other hand, firm B's incentive to invest in quality declines with the inclusion of royalty fees. The optimal quality level for firm

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B is $\beta_R^*(\alpha_R) = \frac{\sqrt{(1-r)\alpha_R}}{\sqrt{k}(3-r)}$, which increases with the quality of firm A's product (due to strategic complementarity) but decreases sharply with the royalty rate (as firm B cannot appropriate all of the return on its quality investment because it must hand over a portion, r, of its revenue to firm A).[11]

Note further that when imposing a royalty fee, firm A offers a higher-quality product but actually charges consumers a lower price (See Table 1.1). This is because firm A seeks to stimulate demand by setting a lower price and can compensate for the decrease in the revenue per unit through the royalty transfer. Firm B, on the other hand, reacts to the price decrease of firm A by raising its price (strategic substitutes). It ends up selling a lower-quality product at a higher price. Royalty fees thus yield a pricing structure that is similar to the razor-and-blades price model that firms selling integrated complements often employ. Because firm A lowers its price more than firm B increases its price, the total price paid by a consumer for both goods is lower. The impact on total price is so dramatic that, although overall product quality is lower, consumers are better off with royalty fees as the expenses they incur drop precipitously. From firm A's standpoint, despite the lower quality of the composite product and the lower price it charges, the royalty arrangement is beneficial because it earns larger profits relative to the case where it did not mandate these fees. Firm B suffers from the implications of these fees and earns lower profits.

To summarize, using a royalty fee structure relieves the value-capture problem for firm A, but does so at the expense of exacerbating the value-creation problem by causing a decline in overall quality provision. In the next section, we show that,

[11] If we substitute firm A's equilibrium quality choice $\alpha_R^* = \frac{\sqrt[3]{9(1-r)}}{\sqrt[3]{4}k(3-r)^2}$ into β_R^*, we find that the total derivative of firm B's quality with respect to the royalty fee is negative. This indicates that the (negative) direct effect of the royalty fee on the quality of product B is stronger than the indirect positive effect through the increase in the quality of product A.

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surprisingly, a direct competitor to firm A can alleviate the value creation problem in a way that leaves all parties better off—including the competing A firms.

1.5 Competition

We now seek to understand how competition in the A market impacts our findings. One might think that such competition could only benefit the B firm because it would reduce firm A's market power. But, as we will show, competition in the A market results in more intricate effects that can alleviate the decline in overall quality and leave all firms better off.

Consider two vertically differentiated firms that produce an A-type product and are denoted A_H and A_L. Let α_H and α_L be the quality levels and p_{AH} and p_{AL} be the prices of the high- and low-quality products in the A market, respectively, where $\alpha_L \leqslant \alpha_H$. There is a single firm that produces the complementary product in two versions, one compatible with the A_H product and the other with the A_L product. The B product's level of quality is again denoted by β. As a result, there are two product pairs available to consumers, $A_H B$ and $A_L B$. Firm B selects a price, p_{BH} and p_{BL}, for each version of its product.

Our focus is on understanding how the existence of competition in the A market affects the actions of the firm that sells the higher-quality A product and of the B firm (these two firms can be thought of as the two players in the analysis of the previous sections). Thus, we treat α_L as exogenous. This would capture, for example, the situation in which a console maker faces competition from personal computers (PCs) that also serve as hardware gaming platforms and it has to take their existence into account along with the game developer's ability to sell PC-compatible titles. To

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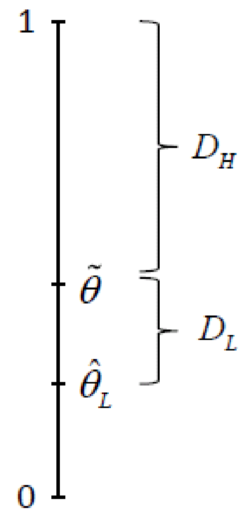

Figure 1.2: Demand Structure When There is Competition in the A Market

simplify our analysis, we further assume that firm B pays royalties only to firm A_H.[12] In Section 1.6 we discuss several extensions and robustness checks to the competitive model setup.

The sequence of moves is similar to that depicted in Figure 1.1, except that firm A_L also prices its product in the final stage. We define $\widehat{\theta}_i$ as the lowest type consumer that gets non-negative utility from purchasing A_iB for $i = \{H, L\}$ and $\widetilde{\theta}$ as the consumer who is indifferent between the high-quality pair and the low-quality pair. We have $\widehat{\theta}_H = \frac{p_{AH}+p_{BH}}{\alpha_H \beta}$, $\widehat{\theta}_L = \frac{p_{AL}+p_{BL}}{\alpha_L \beta}$, and $\widetilde{\theta} = \frac{p_{AH}+p_{BH}-(p_{AL}+p_{BL})}{(\alpha_H-\alpha_L)\beta}$. D_i denotes the demand for A_iB. Figure 1.2 depicts the consumer space and demand structure when $\widetilde{\theta} \geqslant \widehat{\theta}_H \geqslant \widehat{\theta}_L$ is satisfied, which is the condition for both product pairs to have positive sales.

The profit functions in the competitive case for the high-quality A firm, the low-quality A firm, and the B firm are given below. We use superscript CR to denote rel-

[12] This is true, for instance, for video games where the game publisher pays a royalty fee only to the console maker and not to the PC manufacturer for each game title sold.

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evant quantities for the model with competition and royalty payments and continue to use superscript R for the baseline non-integrated model that lacks competition but includes royalty payments (per the solutions in Subsection 1.4.2).

$$\pi_{AH}^{CR} = \left(1 - \widetilde{\theta}\right)\left(p_{AH} + r^{CR} p_{BH}\right) - \frac{1}{3} k \alpha_H^3, \tag{1.6}$$

$$\pi_{AL}^{CR} = \left(\widetilde{\theta} - \widehat{\theta}_L\right) p_{AL} - \frac{1}{3} k \alpha_L^3, \tag{1.7}$$

$$\pi_{B}^{CR} = \left(1 - \widetilde{\theta}\right)\left(1 - r^{CR}\right) p_{BH} + \left(\widetilde{\theta} - \widehat{\theta}_L\right) p_{BL} - \frac{1}{3} k \beta^3. \tag{1.8}$$

The model is solved by backward induction and a numerical example is given in Table 1.3. We next characterize the properties of the unique equilibrium under competition.

Proposition 1.3. *There exists an $\overline{\overline{\alpha}}_L$ such that for $\alpha_L \in (0, \overline{\overline{\alpha}}_L]$, adding a competitor to the A market results in a unique equilibrium in which the profits of all firms, consumer surplus, and social welfare are greater relative to the non-competitive case.*

This result is surprising because it shows that there are conditions under which competition is beneficial for all parties involved, including the direct competitors. Specifically, if the quality of A_L is not too high, there is a *win-win-win-win* situation in which all three firms and consumers are better off.

To understand how such an outcome can arise, we need to examine the impact competition has on firms' desire to invest in quality and on their pricing considerations. As we might expect, competition on the A side of the market drives down the prices of the A products. This in turn gives firm B the opportunity to increase its prices (per strategic substitutability of prices between complementary products) and capture much of the value generated from the complement pairs. Moreover,

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the existence of two product-pair offerings in the market, $A_H B$ and $A_L B$, provides more choices to consumers and, importantly, coupled with lower total prices paid this expands the market and thus renders consumers better off.

Table 1.3: Comparison of Royalty Cases With and Without Competition

	No Competition	**Competition**
Quality	$\alpha_R^* = 1.68$	$\alpha_{CR}^* = 1.69$
	$\beta_R^* = 1.08$	$\beta_{CR}^* = 1.14$
	$q_R^* = 1.81$	$q_{CR}^* = 1.93$
Price	$p_A^{R*} = 0.30$	$p_{AH}^{CR*} = 0.051$
		$p_{AL}^{CR*} = 0.036$
	$p_B^{R*} = 0.75$	$p_{BH}^{CR*} = 0.99$
		$p_{BL}^{CR*} = 0.082$
Royalty Rate	60%	69%
Demand	$1 - \widehat{\theta} = 42\%$	$1 - \widetilde{\theta} = 44\%$
		$\widetilde{\theta} - \theta_L = 15\%$
Profit	$\pi_A^{R*} = 0.157$	$\pi_{AH}^{CR*} = 0.160$
	$\pi_B^{R*} = 0.084$	$\pi_B^{CR*} = 0.099$
Consumer Surplus	0.157	0.206
Social Welfare	0.398	0.465

The numerical values have been calculated assuming $k = 0.1$ and $\alpha_L = 0.25$

But why does the high-quality A firm benefit from competition? In addition to the familiar negative effect of competition, which hurts the A firms through intensified price competition and the division of potential sales between them, competition in

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a market involving complementary products also has an indirect effect on quality decisions. If competition induces higher levels of quality, all firms may benefit from the greater value created.

Proposition 1.4. *For $\alpha_L \in (0, \overline{\overline{\alpha}}_L]$, compared to the case without competition:*

- *Product B's quality is higher: $\beta^{CR*} > \beta^{R*}$.*
- *Product A's quality is higher: $\alpha_H^{CR*} > \alpha^{R*}$.*
- *The quality of the composite good $A_H B$ is higher: $q_H^{CR*} > q^{R*}$.*
- *The high-quality A firm chooses a higher royalty rate: $r^{CR*} > r^{R*}$.*

Proposition 1.4 reveals that competition in the A market can induce firms to offer higher-quality products, thus alleviating the value-creation problem. Firm A_H captures some of this added value through increased consumer demand and the resulting increase in sales, and also through the royalty fees it receives from firm B. As long as α_L is not too high, the negative effect of price competition between the A firms that results in firm A_H getting a smaller share of the pie is overshadowed by the positive effect of higher levels of quality that increase the size of the pie.

Figure 1.3 depicts how the A_H firm's equilibrium profit changes as a result of these two forces. At $\alpha_L = 0$, the model is equivalent to the royalty model without competition that was analyzed in Section 1.4, and $\pi_{AH}^{CR*} = \pi_{AH}^{R*}$. As α_L increases, both the direct negative effect of price competition and the indirect positive effect of rising qualities get stronger– but they do not intensify at the same rate. When α_L is low, the quality improvement effect dominates because firm A_H can achieve relatively high differentiation in the A market by choosing a greater level of quality, thus confining its loss from price competition. In that case, firm A_H benefits greatly from the increase in β and the resulting increase in the quality level delivered by the $A_H B$ product pair. Initially then, $\frac{\partial \pi_{AH}^{CR*}}{\partial \alpha_L} > 0$. However, as α_L increases, firm A_H cannot

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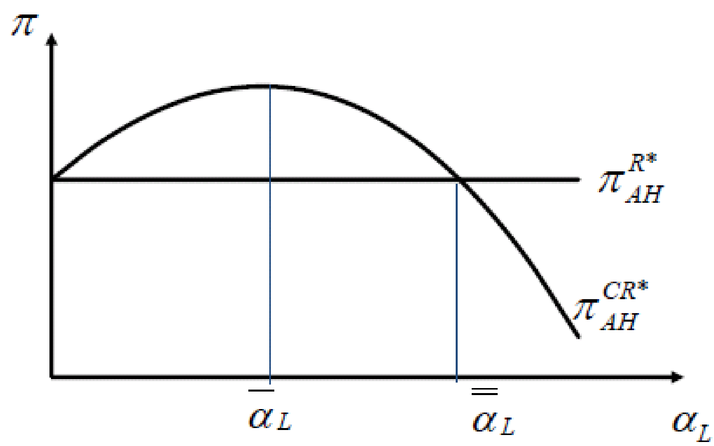

Figure 1.3: Firm A_H's Profits without Competition (π_{AH}^{R*}) and with Competition (π_{AH}^{CR*})

profitably maintain as much differentiation by selecting much higher quality (which comes at an increasing cost), hence price competition between the A firms intensifies and the negative effect of direct competition starts to grow more rapidly than the positive effect of greater total quality provision. At some point, denoted by $\overline{\alpha}_L$ in Figure 1.3, any further increase in α_L will cause π_{AH}^{CR*} to decrease. Eventually, when α_L increases beyond $\overline{\overline{\alpha}}_L$, π_{AH}^{CR*} will be lower than π_{AH}^{R*}. This results in an inverse-U pattern for the profit of A_H as the quality of its rival's product, α_L, increases

We would like to elaborate on the intuition for why firms select higher levels of quality in the presence of a competitor in the A market. First, it is important to stress that competition is a necessary ingredient for the outcome in Proposition 1.3 to hold because it generates a credible mechanism for the appropriate pricing strategies for the A-products in the final stage of the game. In particular, allowing the high-quality A firm to produce its own low-quality variant would not work. To see why, consider the same model as in eq. (1.6)-(1.8) but with the two A products offered by a single

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firm. The profit functions in this case are:

$$\pi_A = \left(1 - \widetilde{\theta}\right)(p_{AH} + rp_{BH}) + \left(\widetilde{\theta} - \widehat{\theta}_L\right) p_{AL} - \frac{1}{3}k\alpha_H^3 - \frac{1}{3}k\alpha_L^3, \tag{1.9}$$

$$\pi_B = \left(1 - \widetilde{\theta}\right)(1 - r)\, p_{BH} + \left(\widetilde{\theta} - \widehat{\theta}_L\right) p_{BL} - \frac{1}{3}k\beta^3. \tag{1.10}$$

Solving for the optimal prices in the last stage of the game, it is straightforward to show (see the Appendix) that the demand structure $\widetilde{\theta} > \widehat{\theta}_H > \widehat{\theta}_L$ is never satisfied in equilibrium, and that the single A firm always prefers to set prices such that the low quality product has no sales. In other words, a monopolist on the A side of the market will never introduce a product line. Firm B obviously realizes this and would not select sufficiently high quality in the preceding stage to ameliorate the value creation problem. In essence, the single A firm cannot commit to prices in the last stage and the win-win-win-win outcome breaks down.[13]

Second, we would like to highlight the interplay between competition and royalty fees, which is again central for the results to hold. For firm B, which now sells two product versions, the market expands and as a result, upfront development costs are spread over more units. This creates an incentive to increase quality. For firm A_H, direct competition from firm A_L generates a desire to increase differentiation, which is accomplished by improving α_H. But to support the necessary R&D investment, while having to drop its price in the face of competition, firm A_H seeks to raise the royalty rate— and this is something that firm B is willing to tolerate because the market has expanded and it has raised its price. Thus, both firms have an incentive to increase quality. Lastly, we note that the high quality of firm B's product and

[13] Our analysis of the A firm's behavior when having the option to introduce a product line thus extends previous literature (e.g., Stockey 1979, Salant 1989, Anderson and Dana 2009), which examines a monopolist's price discrimination behavior, to the case where there is a complement product to pair up with.

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sufficient differentiation by firm A_H ensure that firm A_L can make a positive profits in equilibrium, so it benefits from being an active player in the market.[14]

In sum, the presence of competition in the A market coupled with a royalty-fee structure can have a "coordinating" effect on firms' behavior and ameliorate the value-creation problem to the benefit of all.

1.6 Model Extensions and Robustness Checks

Throughout this essay we made several assumptions to best reflect the phenomena we wished to study and to simplify the analysis. In this section we discuss relaxing several of our main assumptions and extending the model to include additional characteristics. In each case we explain how our results are affected. The formal details of the relevant analyses can be found in the Appendix.

1.6.1 Simultaneous Quality Decisions

We assumed that quality decisions were made sequentially to reflect the reality in many complementary settings. The reader may wonder whether our results change if, instead, firms make quality decisions simultaneously. The analysis of this alternative game structure shows that all the propositions presented in the paper hold and, in fact, the magnitude of the effects described become even more pronounced in the simultaneous case. To understand why, note that when qualities are decided simultaneously both firms are always worse off compared to the sequential development case: each firm would like its counterpart to select a higher quality level but with simultaneous development neither can commit to it. By contrast, when quality deci-

[14] A_L's profits remain positive even if we account for the cost of developing a product with quality α_L in the range $\alpha_L \in [0, \overline{\overline{\alpha}}_L]$.

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sions are sequential, the first mover can credibly commit to a higher quality level, and because quality levels are strategic complements this prompts a higher quality level by the second mover. Thus, although the second mover gains more by being able to free-ride on the first-mover's higher quality, even firm A is better off as its actions induce some quality increase by the B firm (relative to the simultaneous case where free-riding is most extreme). Furthermore, since quality coordination is a more serious problem in the simultaneous case, the effect of a competitor in the A market is even more powerful at relieving the value-creation problem.

1.6.2 Asymmetric Cost Parameters

To avoid any attribution that our findings are due to asymmetries in the firms' cost structutre, we assumed that the development cost parameters are the same for both firms ($k_A = k_B = k$). For completeness, we also solved the case where the firms have different cost parameters ($k_A \neq k_B$). Our analysis shows that the findings in Propositions 1.1-1.4 are qualitatively unaffected by asymmetric quality-development costs. Interestingly, we find that the royalty fees are independent of the cost parameters– hence a situation whereby firm A sets a "negative" royalty rate (i.e., transfers royalty fees to firm B to encourage it to select higher quality if its cost of development is low) cannot arise in equilibrium. That said, with asymmetric cost parameters we are able to characterize conditions under which firm A would find it profitable to develop the complement B product in house. These conditions depend critically on whether royalty fees are charged.

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1.6.3 The Cost of Quality Has a Per-product (Variable) Component

In our analysis, we focused on the development costs associated with improving quality levels and assumed variable production costs were zero. We motivated this assumption with respect to many hardware-software settings. However, the reader may wonder what the implications are of including positive variable costs. To this effect, we examined two model extensions. In the first, we assumed that in addition to the convex development cost incurred as in the model presented in the paper, there is also a marginal cost per unit sold that increases linearly with the product's quality (to reflect the fact that higher quality products are also more costly to manufacture not just develop). Specifically, firm A pays a manufacturing cost of $m\alpha$ for each unit of its product and firm B pays $m\beta$. We find that all the results hold for low enough m values. Since the low-quality product's price is quite low because of competition, an increase in m hurts its producer more compared to the other players; hence after some point the low quality firm cannot break even and thus the three firm equilibrium collapses.

In the second extension, we considered the case in which there is only a variable cost, i.e., there is no upfront investment in quality. For the second order conditions to hold, this marginal cost should be sufficiently convex and we use $\frac{1}{3}m\alpha^3$ and $\frac{1}{3}m\beta^3$. In such a specification, the non-integrated firms choose the same quality levels that the integrated firm chooses, with or without a royalty fee structure. Consequently, there is no value-creation problem. This happens because the margin functions in each model become multiples of each other with constant coefficients once optimal prices are substituted into the profit functions. And this is also true for the demand functions. Hence the first order conditions are maximized at the same quality levels in each case. When facing competition, the high-quality A firm has an incentive

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to set its price and royalty rate such that the low-quality firm has no sales and the win-win-win-win result no longer holds. This is not surprising though, the non-integrated firms already produce the integrated quality level and there is no value creation problem to mitigate through competition.

1.6.4 Non-strict Complementarity: A Flexible Composite Quality Function

The focus of this essay has been to understand the behavior of firms when the products they sell involve two-way complementarity in qualities. To achieve this as cleanly as possible, we chose a model specification that featured strict complementarity ($q = \alpha\beta$). This assumption also approximates many relevant markets. However, in some settings, composite product quality may depend on the separate qualities of each product in additional ways. To explore this issue, we examined a flexible specification in which composite quality is given by $q = z_1\alpha + z_2\beta + z_3\alpha\beta$. In this specification, a consumer can derive utility from using the two products together as well as from using each product by itself. Note that the main model analyzed in the paper is a special case of this general model with $z_1 = z_2 = 0$. This flexible specification also nests the nonessential complements case with $q = z_1\alpha + z_3\alpha\beta$. Analysis of the model with the general function shows that all our results continue to hold as long as there is some degree of complementarity, i.e., z_3 is non-negligible compared to z_1 and z_2. For example, all the findings reported in the paper hold for z_1=$z_2 = 1$ and $z_3 = 3$. Of course, if $z_3 \to 0$ then consumers' utility no longer exhibits interdependence in the qualities of the goods and the forces that stem from complementarity no longer play a dominant role.

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1.6.5 Enriching the Competitive Setup

Our main goal in the analysis of the competitive case was to understand how a low-cost rival in the A market, by virtue of the price pressure it exerts on the high-quality firm, affects firms' incentives to invest in quality and to price products. To focus on these issues, we simplified the setup in a number of ways: assuming the B firm has one quality level, taking as exogenous the quality level of the A_L firm, and not letting the A_L firm impose a royalty fee. We examined relaxing these assumptions one by one. First, let firm B be able to offer two different quality levels, β_H and β_L, the former compatible with the A_H product and the latter with the A_L product. Define the quality ratio $\gamma \equiv \frac{\beta_L}{\beta_H}$ and note that $\gamma \in (0, 1]$. With this specification, the two product pairs available to consumers are $A_H B_H$ and $A_L B_L$. We show that all the results reported in the essay continue to hold in this expanded setting. To see why, note that one can define $\widetilde{\alpha}_L = \gamma\alpha_L$ and replace α_L with $\widetilde{\alpha}_L$ throughout the analysis to reach the equilibrium quality levels and prices. For instance, the relevant region for Propositions 1.3 and 1.4 to hold becomes: $\widetilde{\alpha}_L \in (0, \overline{\alpha}_L] \Rightarrow \gamma\alpha_L \in (0, \overline{\alpha}_L] \Rightarrow \alpha_L \in (0, \frac{\overline{\alpha}_L}{\gamma}]$.

As for the other two issues, both of which involve the A_L firm, numerical analyses show that we can find ranges of the parameter space where the findings in Propositions 1.3 and 1.4 hold. Unfortunately, solving these cases analytically was intractable.

1.6.6 Horizontal Differentiation in the A Market

We modeled competition in the A market as vertical in qualities. Given that in reality competition can be horizontal in nature, we explored whether that form of competition would have similar effects in mitigating the value creation problem. We find that the introduction of an additional horizontally differentiated A firm drives down the prices of the A products. Because of strategic substitutability, the B firm

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increases its price and captures more of the value. This increases firm B's incentive to invest in quality, thus alleviating the value-creation problem as in our vertical model. If the cost parameter, k, is low enough, then the B firm's improvement in quality may more than compensate the original A firm's losses due to price competition. Interestingly, the consumer taste parameter, t, needs to be in a mid-range for the win-win-win-win result to hold. It needs to be low enough to induce price competition between the A firms to incentivize firm B, but it also needs to be high enough so that the loss from price competition is confined.

1.6.7 Other Contractual Agreements Between the Firms

The contractual instrument we studied in this essay was that of a royalty rate. We find that alternative fee arrangements between the complementor firms, such as two-part tariffs, yield similar results. These pricing arrangements can improve performance, but do not succeed in fully coordinating the firms' decisions, and may even exacerbate the quality-gap problem. This failure stems from two sources: First, the firms need to coordinate both their pricing and quality levels. A pricing arrangement that incentivizes the B firm to reduce price towards the optimal level reduces its incentive to increase quality toward the optimal level. Second, the firms set their prices to consumers simultaneously. Thus, in contrast to the case of channel coordination, the A firm never fully commits to its final consumer price at the time of selecting quality, regardless of the pricing arrangement between the firms, and this puts further restrictions on the ability to fully coordinate all the decisions.

In light of the need to coordinate quality in addition to price, we can also consider the possibility that the A firm conditions the arrangement on the B firm's quality. In the most extreme case, the A firm can require the B firm to produce the optimal

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quality and refuse to deal with it otherwise. These types of arrangements fail to achieve full coordination because they are not renegotiation-proof.

1.7 Conclusion

In this essay, we analyzed the strategic interaction between complementor firms that need to make decisions about price and quality and examined the impact of royalty fees and competition on their interactions. Our study has yielded several important insights.

We have shown that an integrated firm is much more effective than non-integrated firms in producing complementary products because the former can internalize all of the gains from its actions. Non-integrated firms, on the other hand, price selfishly (leading to value capture problems) and have an incentive to free-ride on each other's quality investment (leading to value creation problems). We find that these quality levels can be so low that, in contrast to the extant literature, separate firms end up pricing below the integrated firm's price (despite the tendency to price higher for given quality levels). Moreover, the second mover free rides more extensively, resulting in a gap in the qualities of the two complementary firms.

Royalty fees allow the first mover to extract surplus (capture value) from the second mover. As a result, the first mover's profit increases, compensating for the disadvantage of having to set quality first. On the positive side, this induces the first firm (e.g., the hardware producer) to select a higher level of quality for its product. On the negative side, royalties prompt the second firm to shirk even more on quality. Consequently, the quality-gap problem is exacerbated, resulting in even lower quality for the composite product.

We find that one way to benefit from royalty fees, while mitigating the value-

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creation problem, is to have a vertically differentiated competitor. The presence of competition in the A market results in an equilibrium in which all firms and consumers can be better off relative to the case in which only one A firm and one B firm are active. The existence of a lower-quality A firm imposes a credible mechanism to ensure the high-quality firm's price in the final stage, and thus allows the B firm to capture sufficient value such that it is motivated to select a greater quality level than what it would choose without competition— thereby alleviating the value-creation problem. The result is that all three firms share a bigger pie and, in equilibrium, they are all better off. In addition, consumers benefit from the greater value provided and the lower prices the A firms charge. Notably, this outcome cannot be obtained by simply allowing the A firm to introduce a low quality variant— the inability to commit to pricing in the last stage renders such an approach ineffective at inducing the firms to increase their qualities and solve the value creation problem.

These findings present a number of implications for managers. First, for a firm that develops the platform-side of a complement pair and that typically announces its specifications first, our results suggest that mandating a royalty fee is a good way to capture additional value. At the same time, managers of such firms should realize that royalty fees will prompt the other complement producer (the "software" side of the pair) to select a lower level of quality. Hence, royalty fees only work if the firm instituting them increases quality sufficiently and lowers price drastically so that the composite good remains attractive to consumers. Second, we show that royalty fees can be even more conducive for the platform manufacturer in the presence of a competitor. Because the competitor creates an incentive for the complement producer to increase quality, all the firms can benefit. But to obtain this benefit, the platform-side firm must (a) increase quality further (to maintain differentiation from the low-quality

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rival), (b) lower price further (to keep the high-quality pair attractive to consumers in the face of competition), and (c) charge a higher royalty rate (to capture back some of the value from its pro-consumer activities). Thus, while common wisdom might have suggested that facing a direct rival should make a firm worse off, our findings suggest to managers of complementary good firms that they may gain from inviting competition. Furthermore, although an initial reaction to the presence of competition might be to lower the royalty rate to lure firm B to cater more to the high-end A product, the more profitable reaction is to raise the royalty rate while concomitantly investing in greater quality and lowering price. For its part, the B firm should "play along": invest in higher quality and introduce a version of its product that works with the lower-quality A product.

In closing, we acknowledge that our analysis is based on a stylized model that involves a number of simplifying assumptions. We did so to address the quality and pricing decisions of firms that produce strictly complementary products. The focus has been on understanding how various mechanisms and market structures (royalties, competition) could mitigate the value-creation and value-capture problems inherent to complements, particularly for the first mover in the A market. In Section 1.6 we described a number of extensions and robustness checks we examined in detail. However, there remain issues that we leave for future research. The most obvious one is competition in the B market. Intuitively, one would expect such competition to benefit the A firm but leave the original B firm worse off. It is important to note that it is the interplay between facing a direct competitor and being able to charge royalty fees that yields the main result reported in this essay, namely that the firm producing the high-quality product should not oppose but rather welcome entry by a low-quality competitor. In practice, the B firm in a complement market (e.g., a

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software firm) moves second on product design so it typically is not in a position to mandate royalties. Hence, the win-win-win-win result is unlikely to emerge by introducing competition in the B market. We note that if the B market contains multiple products that are sufficiently differentiated horizontally (for example, Guitar Hero in the musing playing genre is a rather unique type of game that does not face direct competition from other games; same is true for Grand Theft Auto in a different genre) all our results continue to hold.

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2. THE ADVERTISING STRATEGIES OF VERTICALLY DIFFERENTIATED FIRMS

2.1 Introduction

> *"We hypothesize that there is a cycle of interplay between display ads, visitation to comparison sites and incremental searches, and ultimately all of these lead to increases in sales."* - Lenovo Marketing Manager (2009)

The online world has created a new environment for informing consumers and generating sales. In this brave new world, firms have websites which allow them to communicate their marketing messages to consumers without contamination from alternative product offerings. In addition, firms can realize sales directly to consumers through their websites and they are increasingly dependent on online sales. For instance, Dell's main sales channel is dell.com and the company's online sales figure totaled $4.8 billion in 2008 (Calnan 2009).

Online advertising is an important vehicle to drive traffic to a manufacturer's website. A firm can inform consumers about its offerings by utilizing display ads on content provider websites or by using sponsored links on search engines. In a recent survey 89% of marketing managers reported that they plan to increase their interactive advertising budget (Forrester 2009). However, being exposed to online ads is not the only way a consumer can learn about products over the Internet. The interactive

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nature of the web facilitates information seeking on offerings and a consumer can do so by visiting a shopping comparison website or performing a search. This dynamic environment brings forth opportunities and challenges to the marketing manager as the Internet becomes the most important medium for reaching today's consumer.

In 2010, for the first time ever, time spent online was higher than time spent watching TV –the previous dominant medium for many decades– for the average US consumer. If the current trends prevail, this gap is expected to exacerbate: time spent watching TV was relatively stable in the last 5 years (a modest 5% increase) while time spent online thrived (121% increase) in the same time period (Forrester 2010). Most US consumers have Internet access as 79% of US households and 40% of mobile phones have Internet connection (comScore 2010). While surfing the web, these consumers actively search for information on goods and sometimes they make purchases: 60% of adults with Internet access report purchasing products online at least once a month (Forrester 2010). Therefore, reaching consumers on the Internet is critical for marketing managers and they employ online advertising ever more. The industry shows strong growth, with last year's (2010) ad revenues soaring by 14.9% to $26 billion (IAB 2011).

The most popular formats to communicate marketing messages online are display advertising and sponsored links on search engines. In 2010, 38% of the online ad industry revenues came from display advertising and 46% came from search engine advertising (IAB 2011). Display advertising takes place on content provider websites such as NYTimes.com, Boston.com and Yahoo.com, and includes banner ads, rich media, digital videos and sponsorships. Display ads are similar to TV or print ads in the sense that consumers' main motivation is content consumption and they are exposed to ads in the meantime. This makes display advertising a convenient tool

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to build interest in a product. In Kotler's (2003) framework presented in Figure 2.1, display advertising may trigger consumers to realize a need, hence lead them to Stage 1, problem recognition. Alternatively, by advertising on a search engine a firm can reach consumers that are already interested in a product category and are hence in Stage 2, information search. When a user performs a search on a website such as Google.com or Bing.com via keywords, suggesting she is interested in learning more about a particular product type, the search engine provides a list of manufacturers' sponsored link ads in addition to organic links that might include manufacturer websites, product review/comparison websites and e-tailer websites.

A common feature of these different advertising formats is that they are interactive. Consumers can click on an online ad, whether display or sponsored link, and be directed to the advertiser's website where they can learn about the advertiser's product. This is advantageous for the advertiser because at the website consumers are exposed to further marketing messages without contamination from information on rival products. Moreover, consumers may even make a direct purchase from the website. Given the benefits of having more consumers browse the manufacturer's website, advertising effectiveness is vital for the success of an online ad. For example, if display advertising is effective, consumers that attend to the ad have a greater chance of visiting the advertiser's website. Exposure to the ad combined with further marketing messages at the advertiser's website may facilitate a brand's entrance to a consumer's consideration set. On the other hand, the display ad may also initiate a general interest in the product category and trigger some consumers to search for alternative offerings. Similarly, if a search engine ad is effective, consumers have a greater probability to click on it and consequently have the advertised brand in their consideration set. Nevertheless, some consumers will scroll down and check out the

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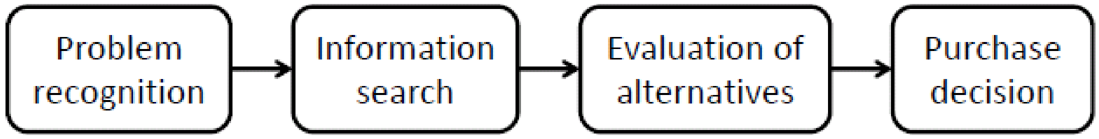

Figure 2.1: The Consumer Buying Process, Adapted from Kotler (2003)

organic links that might have information on alternative products. From this point of view, both display advertising and search engine advertising can create informational disparity in the marketplace that results in asymmetric consumer consideration sets.

While both ad formats can produce informational disparity, they are fundamentally different in the way ad space is allocated to advertisers. Display advertising space is sold on a cost-per-mille (CPM) basis: a firm that wants to advertise on a content provider's website buys a number of impressions in bulk and the advertising campaign lasts until the ad downloads that many times. Search engine advertising space, on the contrary, is allocated through an auction mechanism: a new, separate auction is run each time a consumer performs a search and a firm that has a greater valuation will bid higher for acquiring a better position. The discrepancy in the duration of each ad format has an effect on the strategic decisions of firms that wish to advertise. For instance, a firm that is running a display advertising campaign over a few weeks can change the price of its product over that period of time, while price is stickier for a firm that is bidding in an instantaneous search engine auction.

The focus of this essay is on the interaction between firms that advertise and sell their products primarily over the Internet. We concentrate on goods for which relevant information for a purchase decision is available online without the need to inspect the good physically in a brick and mortar store. In Lal and Sarvary's (1999) context, the purchase decision for the products in our study primarily depends on

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digital attributes as opposed to nondigital ones. The top 2 growing online retail product categories in 2010 were consumer electronics and computer hardware, with 19% and 17% growth rates, respectively (comScore 2010.) Digital attributes, such as processing power in laptops or image resolution in digital cameras, are crucial in evaluating these goods and better performance on digital attributes is typically more desired. Therefore, in this paper, we concentrate on firms that produce vertically differentiated goods.

A marketing manager that wants to promote a product like a Lenovo laptop needs to make a decision on its online presence. It can act passively and depend on shopping comparison websites, e-tailer websites and on organic links in search engines that feature information on Lenovo products. Consumers that are interested in the laptop category may learn about Lenovo laptops from any of these sources. On the one hand, this method has the advantage of being free. On the other hand, one should also consider that at the review/comparison and e-tailer sites consumers will also be exposed to alternative products that may be of higher-quality. Alternatively, a more proactive method to reach consumers would be to advertise online. Doing so ensures that one's brand will be in all consumers' consideration sets, but this might start a price war if all firms advertise and quality differentiation is low. Whilst developing an online advertising strategy, the manager needs to balance these considerations.

Both display ads and sponsored links are alike in the sense that they can divert consumers' browsing paths to the manufacturer's website. However, the different methods of selling ad space for each of these formats and consequently the difference in duration of advertising campaigns is an issue to consider. Last but not the least, the marketing manager also needs to take into account rivals' expected actions. For instance, running a display ad campaign while the rival does not advertise may create

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an informational disparity in the number of consumers that consider only the firm's product. In search engine advertising, getting the most desirable top link may have an additional benefit of pre-empting a rival from attaining it.

In this essay we study strategic online advertising decisions by two vertically differentiated firms, focusing on the following research questions:

- What governs the incentives to advertise online, given the various formats like display ads and sponsored links?
- Should we always expect a high-quality firm to advertise? When can we see ads from a lower-quality firm?
- Does greater advertising effectiveness always hurt the non-advertising firm?
- If quality decisions are endogenous do firms maintain more or less differentiation when adverising online compared to a full information model?

To answer these questions, we construct a stylized model in which two vertically differentiated firms can promote their products online using display or search engine advertising. Through their strategic advertising decisions, firms can create informational disparity in consumers' consideration sets. Advertising effectiveness determines the ratio of consumers who click on the ad and browse the advertiser's website. Remaining consumers can learn about the rival firm's product as well; for instance, they can visit a shopping comparison website for a comparison of alternatives.

The analysis reveals that the attractiveness of advertising for a firm depends on the level of quality differentiation. If vertical differentiation is small and consumers are informed about both goods, price competition between the firms is fierce. This

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creates an incentive for informational disparity. When some consumers have only one of the products in their consideration set, the manufacturer of that good can increase price in order to skim their surplus. This alleviates price competition and hence makes informational disparity appealing to the non-advertising firm, even though it means that some consumers will not be aware of its product.

Specifically, with display advertising a low-quality firm may elect not to advertise, even at zero cost, if its product is not differentiated enough from its rival's. When consumers are fully informed, the low-quality firm is at a great disadvantage because of intense price competition. Therefore, the low-quality firm may be better off in a situation in which the high-quality firm is the only advertiser compared to a case in which both firms advertise. Moreover, in an equilibrium in which the high-quality firm is the only advertiser, an increase in advertising effectiveness may actually enhance the low-quality firm's profit because of the corresponding increase in the level of informational disparity.

With search engine advertising, a firm can achieve a favorable position by acquiring the top sponsored link on the search results page. This is decided by an auction and firms' bids are determined by their valuation of attaining the top link. The high-quality firm usually has an incentive to outbid its rival. However, we show that if advertising effectiveness is moderate and vertical differentiation is small then the low-quality firm obtains the top link and price competition is mitigated.

If quality decisions are endogenous, informational disparity reduces competition and results in less differentiation in the marketplace in each case compared to a full information model. This occurs because the firms can substitute informational differentiation instead of quality differentation. This reduction in differentiation is greater in the search engine advertising case than display adverising case, as the

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auctions allow price commitment.

The rest of the essay is organized as follows. In the next section we relate our work to the extant literature. Section 2.3 sets up the model and presents the classic vertically differentiated duopoly as a benchmark. Sections 2.4 and 2.5 analyze display advertising and search engine advertising, respectively. Section 2.6 investigates endogenous quality decisions. Section 2.7 concludes and provides managerial implications. All proofs have been relegated to the Appendix.

2.2 *Related Literature*

The tremendous growth, over 300% in the last ten years, of the online advertising industry has correspondingly elicited scholarly work on the topic. For a detailed description of the industry including a review of display and search advertising see Evans (2008, 2009). The author provides a detailed account of business models, ways of allocating advertising space and pricing of ad space for both types of online advertising. Parallel to the increase in online advertising spending, a desire to understand how firms should best allocate their resources has arisen, particularly concentrating on advertising effectiveness.

The interactive nature of the web has provided a new metric for measuring the effectiveness of online ads: click through rates (CTR). To discriminate between attended and non-attended ads, CTR is often utilized (for example, Novak and Hoffman 2000 and Dahlen 2001). Although in some cases the immediate CTR is low (Dreze and Hussherr 2003), Rutz and Bucklin (2009) find that banner ads influence consumers' subsequent browsing behavior by increasing their likelihood of seeking information on an advertised brand. Further research shows that exposure to display ads increases brand awareness, site visits and purchases (Ilfeld and Winer 2002, Sherman

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and Deighton 2001, Manchanda et al. 2006). In our paper, we assume that exposure, immediate clicks and subsequent longer-term site visits help get an advertiser's product in consumers' consideration sets and hence might lead to a purchase; and define that as ad effectiveness.

The research on search advertising has mostly concentrated on the auctioning of keywords (Varian 2007, Edelman et al. 2007, Katona and Sarvary 2010). In these papers, firms have a constant value for each of the sponsored link positions and the focus is on the bidding behavior according to these exogenous values. However, in our paper, we are interested in strategic interaction among advertisers in the product market; therefore the values of the positions are endogenous and depend on product market competition. For instance by acquiring the top link, in addition to the usual benefit of informing consumers about its own offering, a firm also prevents its competitor from attaining this coveted spot.

In this essay, we adopt an informative view of advertising (see Bagwell 2007 for an exhaustive survey of views on advertising). There is a rich literature on how firms select the level of informative advertising (e.g. Butters 1977, Grossman and Shapiro 1984), but in this literature products are either homogeneous or differentiated horizontally. Our focus is on advertising decisions of firms that sell vertically differentiated goods. Another stream of literature studies advertising in the context of vertically differentiated firms (e.g. Nelson 1970, Milgrom and Roberts 1986). These papers treat advertising as a signal of quality and find that high-quality firms advertise more. However in our paper, consumers are not uncertain of a product's quality, provided they are informed about it. In other words, digital attributes (Lal and Sarvary 1999) determine the value of a good for the consumers in our study, but advertising can effect which products are considered.

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2.3 Model Setup

2.3.1 Firms and Products

Consider a market with two firms, indexed 1 and 2, each offering a vertically differentiated product. The firms are differentiated on a single attribute which we call quality and this attribute determines the value of each good to consumers. The quality level of product i is denoted v_i and without loss of generality we assume that firm 1 is the high-quality manufacturer. The price of product i is denoted p_i and we assume zero marginal cost of production for both firms.

2.3.2 Websites

The firms operate online; that is, each firm maintains a website and sells its product to consumers directly through it. In addition to firms' sites, there are 3 more type of websites that provide information on product offerings: content websites, search engines and shopping comparison websites. The first two websites attract consumers by providing content and search results, respectively, and sell ad space to the firms. The ads on the content provider websites are display ads and the ads on the search engine are sponsored links. If a consumer clicks on either of these online ads, she is transferred to the advertising firm's website. There is also information on both firms' goods on shopping comparison websites. After being exposed to an ad, consumers may decide to visit the comparison site in order to learn about the products in the market.[1]

[1] Our focus is on products that are mainly purchased online; however, some consumers may decide to visit brick and mortar stores upon seeing an ad. Consumers that physically visit a retailer will be exposed to alternative products on the shelf and/or by the salespeople. These consumers will be equivalent to the group that visits comparison websites and will have both goods in their consideration sets. Similarly, consumers that go to an offline store that carries a single brand, such as an Apple store, will be equivalent to the group that visits a manufacturer's website and will have only the manufacturer's

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2.3.3 Consumers

We assume that the market is composed of a unit mass of consumers that have the same preference ordering among the products when offered at the same price. All consumers prefer higher over lower-quality, but they are heterogeneous in their willingness to pay for quality. The marginal valuation of quality, θ, is distributed uniformly on [0,1]. The utility a consumer of type θ derives from buying product i is $U_i = \theta v_i - p_i$ while the utility from not purchasing, U_0, is normalized to zero. A consumer buys at most one unit and prefers the good that provides greater utility. However, a consumer can only purchase a product that she is informed about. That is, consumers first form consideration sets and then decide to purchase or not from that set (Moe 2006). Consumers are prompted to get information on a product in two ways: they might be exposed to an online ad or they might actively search for information on a search engine or a shopping comparison website.

2.3.4 Benchmark: Vertically Differentiated Duopoly

We use the classic vertically differentiated duopoly model (Shaked and Sutton 1982, Moorthy 1988) as the benchmark. In this model, consumers are assumed at the outset to be fully informed about firms' offerings and they have both products in their consideration sets; hence firms do not engage in advertising to inform them. In order to solve the benchmark case, we first find the marginal consumer who is indifferent between buying a product or not. For instance the valuation of the marginal consumer for product i, θ_i, satisfies $U_i = \theta_i v_i - p_i = U_0 = 0$. Thus, all consumers who have a higher valuation, $\theta > \theta_i = \frac{p_i}{v_i}$, derive positive utility from product i. The valuation of

product in their consideration sets. Analyzing a model with both online and offline purchases is beyond the scope of this essay.

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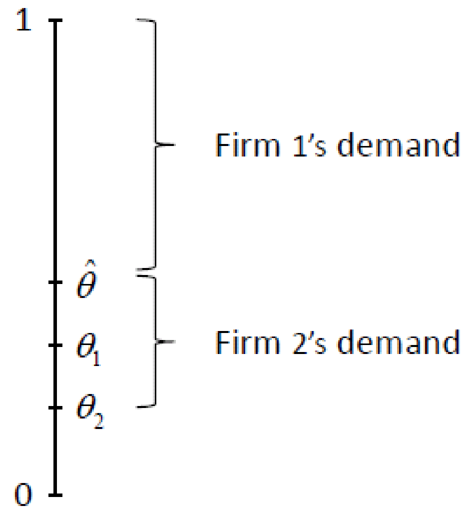

Figure 2.2: Benchmark Case Demand Structure

the marginal consumer between products 1 and 2, $\widehat{\theta}$, satisfies $U_1 = \widehat{\theta}v_1 - p_1 = U_2 = \widehat{\theta}v_2 - p_2$. Thus, consumers that have valuation greater than $\widehat{\theta} = \frac{p_1 - p_2}{v_1 - v_2}$ prefer product 1, and the rest of the consumers prefer product 2, as long as they get positive utility from purchase. Firm 1's demand is $x_1 = [1 - \widehat{\theta}]$ and firm 2's demand is $x_2 = [\widehat{\theta} - \theta_2]$ (see Figure 2.2). Note that this demand structure is realized if $\theta_1 > \theta_2$. If this were not true, firm 2's product would be dominated because any consumer who derives positive utility from product 2 would get greater utility from product 1. Hence firm 2 never selects a price that is too high in equilibrium and this ensures that $\theta_2^* = \frac{p_2^*}{v_2} < \theta_1^*$ holds.

The corresponding profit functions are:

$$\pi_1^B = (1 - \widehat{\theta})p_1 \tag{2.1}$$

$$\pi_2^B = (1 - \widehat{\theta})p_2 \tag{2.2}$$

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The equilibrium prices and profits are given in Table 2.1 under the heading "Benchmark".

Table 2.1: Display Advertising Equilibrium

	Benchmark	**Display**	
Advertiser		**Firm 1** $\left(\frac{v_1}{v_2} \leqslant 1 + \frac{3\sqrt{1-\beta}}{4}\right)$	**Both** $\left(\frac{v_1}{v_2} \geqslant 1 + \frac{3\sqrt{1-\beta}}{4}\right)$
p$_1$	$p_1^B = \frac{2v_1(v_1-v_2)}{4v_1-v_2}$	$p_1^{D1} = \frac{2v_1(v_1-v_2)}{4v_1-v_2-3\beta v_2}$	$p_1^B = \frac{2v_1(v_1-v_2)}{4v_1-v_2}$
p$_2$	$p_2^B = \frac{v_2(v_1-v_2)}{4v_1-v_2}$	$p_2^{D1} = \frac{v_2(v_1-v_2)}{4v_1-v_2-3\beta v_2}$	$p_2^B = \frac{v_2(v_1-v_2)}{4v_1-v_2}$
x$_1$	$x_1^B = \frac{2v_1}{4v_1-v_2}$	$x_1^{D1} = \frac{2(v_1-\beta v_2)}{4v_1-v_2-3\beta v_2}$	$x_1^B = \frac{2v_1}{4v_1-v_2}$
x$_2$	$x_2^B = \frac{2v_1}{4v_1-v_2}$	$x_2^{D1} = \frac{v_1(1-\beta)}{4v_1-v_2-3\beta v_2}$	$x_2^B = \frac{2v_1}{4v_1-v_2}$
ß$_1$	$\pi_1^B = \frac{4v_1^2(v_1-v_2)}{(4v_1-v_2)^2}$	$\pi_1^{D1} = \frac{4v_1(v_1-v_2)(v_1-\beta v_2)}{(4v_1-v_2-3\beta v_2)^2}$	$\pi_1^B = \frac{4v_1^2(v_1-v_2)}{(4v_1-v_2)^2}$
ß$_2$	$\pi_2^B = \frac{v_1v_2(v_1-v_2)}{(4v_1-v_2)^2}$	$\pi_2^{D1} = \frac{v_1v_2(v_1-v_2)(1-\beta)}{(4v_1-v_2-3\beta v_2)^2}$	$\pi_2^B = \frac{v_1v_2(v_1-v_2)}{(4v_1-v_2)^2}$

Superscript D_i denotes the Display Advertising case in which only firm i advertises. Superscript B denotes the Benchmark case or the Display Advertising case in which both firms advertise. Note that in both of these two cases consumers are fully informed and the equilibrium values are the same.

2.4 *Display Advertising*

In this section, contrary to the benchmark case, we assume that consumers are not initially aware of the products. However a firm may inform consumers about its offering through display advertising. Let there be a content provider website that consumers visit regularly. This website sells ad space to firms and each firm can decide to execute a display advertising campaign on the content provider's website.

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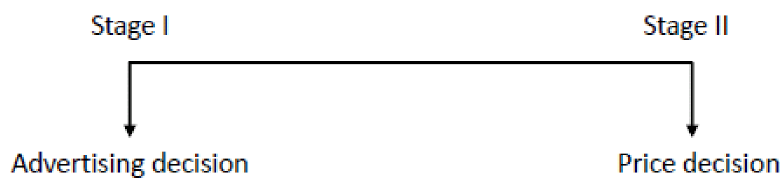

Figure 2.3: Display Advertising Timeline

Display ad space is sold by the cost per mille method, usually in the order of millions of eyeballs.[2] Because of this, a display ad campaign typically runs for an extended period of time until the number of impressions (measured by downloads) are shown. In order to model this, we devise a two stage game. In the first stage the firms decide whether to advertise or not and in the second stage they set prices (see Figure 2.3). This setup reflects the fact that price is relatively easy to change and firms can modify their prices during the course of an advertising campaign. The cost of running a display advertising campaign is C, and without loss of generality it is normalized to zero.[3]

We assume that if a firm decides to advertise, all consumers in the market are informed about its product. In other words, the advertiser's product automatically gets in the consideration sets of consumers. Trivially, if neither firm advertises, both firms will face zero demand as consumers' consideration sets will be empty. If both firms advertise, all consumers will be informed about both goods and consequently, the outcome will be the same as the outcome of the benchmark case (presented in subsection 2.3.4.)

A more interesting situation arises when only one firm, say firm i, advertises. In

[2] For example, Yahoo.com has a minimum limit of 500,000 eyeballs if a firm wants to purchase display ad space on its homepage.

[3] Allowing C to be positive would not change our results as long as it is not too high.

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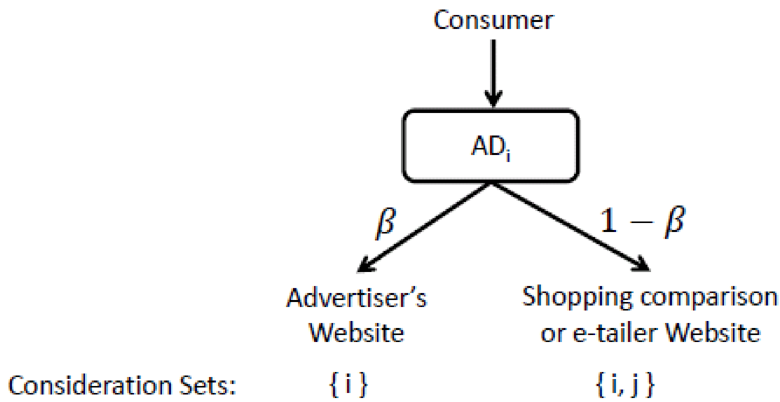

Figure 2.4: Display Advertising - Firm *i* Advertises

this case all consumers will become aware of product *i*. Some consumers may click on the ad and be directed to firm *i*'s website where they can learn more and possibly purchase firm *i*'s product. We define display advertising effectiveness, β, as the percent of consumers who end up with only the advertiser's brand in their consideration set. The remaining consumers may choose to learn about the alternative products in the category when responding to the ad and visit the comparison websites. These consumers will have both products in their consideration set. As can be seen in Figure 2.4, such firm actions will generate an informational disparity between the consideration sets of consumers.

Several of our model assumptions merit further discussion. First, for simplicity, we assume that all consumers respond to the ad in some way. In reality, upon being exposed to a display ad, a number of consumers will respond to the ad and take action while the remaining consumers simply ignore the ad. We are interested in only the consumers that take action after seeing the ad, and normalize the size of this group to one. This way, we can focus on subsequent browsing behavior of consumers that are

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triggered by the ad and realize a need for a product. In other words, we distinguish between advertising responsiveness and advertising effectiveness. Second, we assume that advertising effectiveness determines the outcome of the actions consumers take upon seeing an ad. For instance, if a consumer is interested in the specific brand advertised, she clicks on the ad and is immediately transferred to the advertiser's website. In fact, the benefit of a display ad is not limited to that; there is evidence that banner ads influence more than half of the consumers' subsequent browsing behavior by increasing the chance that they visit webpages that contain information on the advertised product (Rutz and Bucklin 2009). We simply refer to these consumers' longer-term visitations also as clicks. Third, we assume that consumers who click on the ad and visit the advertiser's website have only the advertised brand in their consideration set. Naturally, there will be consumers who do not stop there and visit the comparison site as well. In our model these consumers are simply in the $1-\beta$ percent of the consumers. One could easily micro model these consumers of size y, by creating a new variable $\beta' = \beta - y$ with β' being the adjusted advertising effectiveness (so that $1-\beta' = 1-\beta+y$). This specification would not change our results. In summary, we simply refer to advertising effectiveness as the percent of consumers who end up with only the advertiser's product in their consideration set.[4]

We solve the model through backwards induction. If neither firm advertises, both firms face zero demand and charge the marginal cost that is equal to zero. If both firms advertise, all consumers are fully informed and the firms will choose the prices as in the benchmark case. However if only one firm, say firm i, advertises, there will be an informational disparity: β percent of consumers will only consider product i

[4] It is possible to have distinct advertising effectiveness level for each firm such as β_1 and β_2. However, we want to avoid asymmetric outcomes due to asymmetric advertising effectiveness. Moreover, in order to concentrate on pure strategy equilibria, we assume that advertising effectiveness has an upper limit depending quality level of each product, $\beta < \overline{\beta}(v_1, v_2)$.

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and $1-\beta$ percent of consumers will have both goods in their consideration sets. In order to set the profit maximizing price, firm i needs to consider profits from both of these segments. Had firm i been operating only in the β sized market of consumers that click on its ad, the optimal price would be the monopoly price, $\frac{v_i}{2}$. Conversely, had firm i been operating only in the $1-\beta$ sized market of consumers that are aware of both products, the optimal price would be the benchmark price, p_i^B. Nevertheless the firm operates in both markets and needs to quote a single price on its website. The profit maximizing price will be less than the monopoly price and greater than the benchmark price. The following Proposition shows that the equilibrium price depends on the size of each segment –hence on advertising effectiveness– and quality differentiation between the goods. The equilibrium expressions are given in Table 2.1 under the heading "Display".

Proposition 2.1. *The high-quality firm always advertises, the low-quality firm advertises only when quality differentiation is large enough such that* $\frac{v_1}{v_2} \geqslant 1 + \frac{3\sqrt{1-\beta}}{4}$.

Proposition 2.1 is the result of a trade-off between the gain from reduced price competition and the loss from potential demand. Since the cost of advertising is zero, one could intuit that it is always a dominant strategy to advertise. Consider that this is the case and that both firms advertise; resulting in the benchmark equilibrium in which price competition is severe as consumers are fully informed. In this situation, by not advertising, a firm can create an informational disparity that will lessen price competition. Of course, not advertising also means that β percent of consumers will not be informed about the firm's product, and consequently there is a loss in potential demand. Therefore, when the firms are deciding whether to advertise or not, they need to consider the benefit from the potential informational disparity that arises in terms of reduced price competition. Specifically, if vertical differentiation is small, the

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low-quality firm elects not to advertise and foregoes the chance to inform a β portion of consumers, even though advertising is costless. However, it is dominant for the high-quality firm to advertise. This happens because the cost of losing potential demand is much smaller for the low-quality firm. Indeed from the benchmark case we know that losing a potential customer is at least 4 times costly for the high-quality firm compared to the low-quality firm.[5] Thus, when price competition intensifies, i.e., when vertical differentiation is small, the low-quality firm is more willing to sacrifice potential demand in order to soften price competition and it achieves this by not advertising. The high-quality firm anticipates this decision and advertises even when vertical differentiation is minimal.

The trade-off for the low-quality firm is evident in the inequality given in the proposition. The ratio $\frac{v_1}{v_2}$ is a measure of quality differentiation and the right hand side decreases in β. In words, if advertising effectiveness is high, the low-quality firm is more likely to advertise even when vertical differentiation is small because not advertising means that a large number of potential customers will not be aware of its product. At the limit case when $\beta = 1$, the right hand side is equal to 1 and the low-quality firm will always advertise. At the other limit ($\beta \to 0$), the maximum value of the right hand side is $\frac{7}{4}$, which means that if there is sufficient quality differentiation ($\frac{v_1}{v_2} \geqslant \frac{7}{4}$) the low-quality firm will advertise even when advertising effectiveness is very low. In summary, if there is sufficient vertical differentiation, both firms will advertise and the equilibrium will be as in the benchmark case. However, if quality differentiation is small and advertising effectiveness is not too high, the low-quality firm will adopt a "passive" advertising strategy –not advertise– and depend on the

[5] When all consumers are informed about both products (as in the benchmark case), in equilibrium, we have $x_1^* = 2x_2^*$ and $p_1^* > 2p_2^*$. A potential customer's type is $\theta \sim U[0,1]$. This means that a potential customer that is aware of both products is two times more likely to buy from firm 1 and pays at least two times p_2^*.

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consumers who visit shopping comparison websites.[6] Moreover, the low-quality firm may even be better off with an increase in advertising effectiveness in such a case:

Proposition 2.2. *The low-quality firm's profit increases in advertising effectiveness when quality differentiation is small. That is* $\frac{\partial \pi_2^{D1}}{\partial \beta} > 0$ *for* $\frac{v_1}{v_2} < 1 + \frac{3(1-\beta)}{4}$.

Proposition 2.2 states that, when vertical differentiation is small, i.e., in the region where the low-quality firm does not advertise per Proposition 2.1, the low-quality firm's profit may actually increase in advertising effectiveness (See Figure 2.5).[7] This is surprising because in this region only the high-quality firm advertises and a greater advertising effectiveness means that the proportion of consumers that only consider the high-quality product is larger, while the proportion of consumers that also consider the low-quality product is smaller. That is, the low-quality firm might be better-off if more consumers have only the high-quality product in their consideration sets. This result is due to the impact of informational disparity on price competition. When quality differentiation is small, prices are very close to marginal costs and the profits are very low. In such a case, an increase in advertising effectiveness leads to a greater level of informational disparity and alleviates price competition because it prompts the high-quality firm to raise price. This allows the low-quality firm to raise price as well, and consequently its equilibrium profit increases. In other words, the low-quality firm might be better-off if fewer consumers have its product in their consideration sets.

[6] On a technical note, if advertising effectiveness is high, i.e., $\beta > \overline{\beta}(v_1, v_2)$, there is no pure strategy equilibrium in the system because the best response functions of the firms do not intersect when the low-quality firm is the only advertiser.

[7] Note that $1 + \frac{3(1-\beta)}{4} \leqslant 1 + \frac{3\sqrt{1-\beta}}{4}$.

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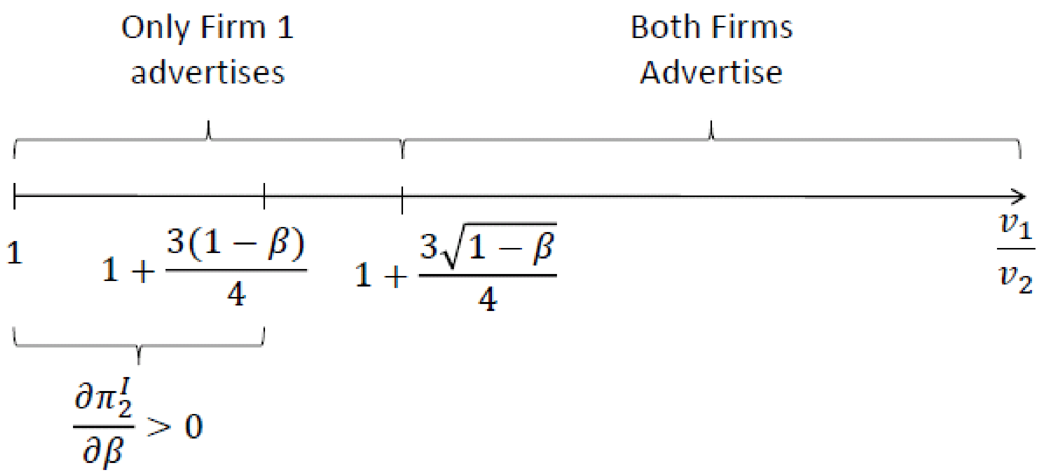

Figure 2.5: Display Advertising Outcome

2.5 *Search Engine Advertising*

In this section we assume that consumers are already interested in the category at hand, but they are unaware of specific brands. In order to learn more, they perform a search on the product category. The search engine provides a results page that includes sponsored links and organic links. The sponsored links are basically advertisement space sold by the search engine. These links transfer consumers that click on them to the advertiser's website. On the other hand, organic links direct consumers to webpages that previous searchers with the same query most often selected to visit.

When a popular keyword is typed in, the search engine almost always presents a few sponsored links at the top of the search results page. There is consensus among industry experts, advertisers and scholars that the first position is the most desirable one on the sponsored links list (Evans 2008). The first link the consumers see, the top sponsored link, has the highest probability of being attended to. Our focus is on firms' desire to be placed at top of the sponsored link list, and we assume that all consumers

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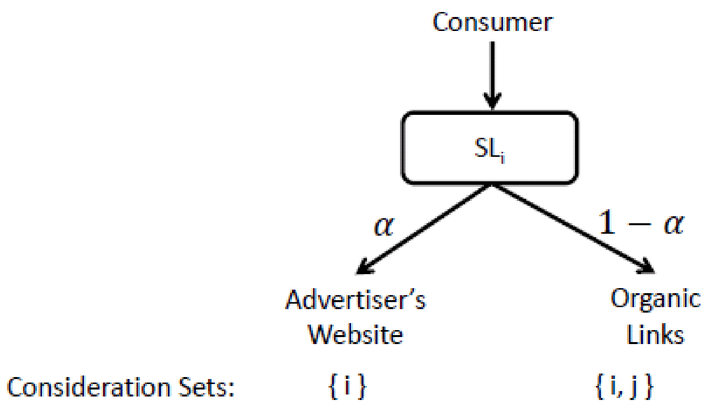

Figure 2.6: Search Engine Advertising - Firm *i* Has the Top Link

become aware of the brand that has acquired this link. Consequently, we define search engine advertising effectiveness, α, as the percent of consumers who click on the top link, visit the advertiser's website and have its product in their consideration set. If the top link fails to be a good enough hook for some consumers, they will gaze down to the other links which could be sponsored (e.g., alternative good's advertisement) or organic (e.g., product review sites, e-tailer sites, manufacturer sites) and they will be informed about the alternative product as well. Therefore, $1-\alpha$ proportion of consumers have both brands in their consideration sets.[8] This is captured in Figure 2.6; attaining the top sponsored link can create favorable informational disparity for a firm in the market. Also note that there can be only one firm that acquires the top link, in contrast to the general display advertising model in which both firms could have advertised at the same time on a content provider's website.

We focus on the strategic interaction of two vertically differentiated firms and the

[8] If there are consumers who visit other links in the search results page in addition to the top link advertiser's website, they learn about the alternative product as well; therefore they are part of the $1-\alpha$ segment of consumers.

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prospects of informational disparity; hence we will not investigate the details of the auction mechanism. The firms in our model are differentiated only in quality, so we will assume that they are similar in all other respects that the search engine evaluates them on when deciding the order of the sponsored links.[9] This will enable us to make the simplification that whichever firm has a higher value for the top link bids more than its opponent and wins the auction (Edelman et al. 2007). We assume that the search engine runs a second price auction, meaning that the firm that has the higher bid wins the top link but pays an amount equal to the next highest bid.[10] Since these firms are the only firms in this product category, we assume that no other party bids in the auction (i.e., wants to be associated with the relevant keywords).

In order to figure out a firm's valuation for having the top link, we need to consider the difference in its profit between two alternative cases: when it has the top link and when its opponent has the top link. For instance, the value of the top link for firm i would be $\pi_i^i - \pi_i^j$, where the superscript denotes the firm that has secured the top link. Firm 1 wins the auction when its value is higher than firm 2, i.e.,

$$\pi_1^1 - \pi_1^2 > \pi_2^2 - \pi_2^1. \tag{2.3}$$

Rearranging Equation (2.3) we get:

$$\pi_1^1 + \pi_2^1 > \pi_1^2 + \pi_2^2. \tag{2.4}$$

[9] Search engines allocate the positions on the sponsored links list to the advertisers via a complicated bidding system. Their algorithm makes use of amount bid, click through rates and a "quality score" of the advertiser. For some papers that deal with the details of this bidding system and how positions are allocated see, Edelman et al. 2007, and Katona and Sarvary 2010.

[10] This is not a critical assumption. The outcome is the similar for any auction mechanism in which the winner is the highest valuation party.

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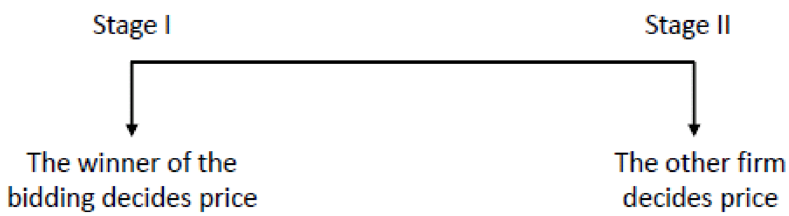

Figure 2.7: Search Engine Advertising Timeline

Thus, the winner of the top link can be determined by a comparison of total industry profits. If the total profit of the two firms is greater in the case where firm 1 acquires the top link compared to the case where firm 2 acquires it, then firm 1 will win the auction and the reverse is true otherwise.

In contrast to a display advertising campaign, where firms buy millions of eyeballs that typically last for some time, an auction takes place each time a consumer performs a search. Therefore, the sponsored link advertising decision has a much shorter duration –almost instantaneous– compared to display advertising. For example, Google.com executes 4 auctions per second for the keyword "laptop". This fast pace leaves no time for price adjustment; the firm that has higher value for the top link, say firm i, decides on price at the same time it places a bid on the auction. The firm that has lower value, firm j, will not win the top link and it has more leeway in setting the price. We model this by making firm j set its price after the winner of the auction is determined (See Figure 2.7).

We solve the model through backwards induction and the equilibrium results are given in Table 2.2 under the heading "Search Engine".

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Table 2.2: Search Engine Advertising Equilibrium

	Benchmark	**Search Engine**	
Top Link		**Firm 1** $\left(\alpha \notin [\overline{\alpha}, \overline{\overline{\alpha}}] \wedge \frac{v_1}{v_2} < \overline{v}\right)$	**Firm 2** $\left(\alpha \in [\overline{\alpha}, \overline{\overline{\alpha}}] \vee \frac{v_1}{v_2} < \overline{v}\right)$
$\mathbf{p}_1$	$p_1^B = \frac{2v_1(v_1-v_2)}{4v_1-v_2}$	$p_1^{S1} = \frac{v_1(v_1-v_2)}{2v_1-v_2-\alpha v_2}$	$p_1^{S2} = \frac{v_1}{2}$
$\mathbf{p}_2$	$p_2^B = \frac{v_2(v_1-v_2)}{4v_1-v_2}$	$p_2^{S1} = \frac{v_2(v_1-v_2)}{2(2v_1-v_2-\alpha v_2)}$	$p_2^{S2} = \frac{v_2}{2}$
$\mathbf{x}_1$	$x_1^B = \frac{2v_1}{4v_1-v_2}$	$x_1^{S1} = \frac{1}{2}$	$x_1^{S2} = \frac{1-\alpha}{2}$
$\mathbf{x}_2$	$x_2^B = \frac{2v_1}{4v_1-v_2}$	$x_2^{S1} = \frac{v_1(1-\alpha)}{2(2v_1-v_2-\alpha v_2)}$	$x_2^{S2} = \frac{\alpha}{2}$
ß$_1$	$\pi_1^B = \frac{4v_1^2(v_1-v_2)}{(4v_1-v_2)^2}$	$\pi_1^{S1} = \frac{v_1(v_1-v_2)}{2(2v_1-v_2-\alpha v_2)}$	$\pi_1^{S2} = \frac{(1-\alpha)v_1}{4}$
ß$_2$	$\pi_2^B = \frac{v_1 v_2(v_1-v_2)}{(4v_1-v_2)^2}$	$\pi_2^{S1} = \frac{v_1 v_2(v_1-v_2)(1-\alpha)}{4(2v_1-v_2-\alpha v_2)^2}$	$\pi_2^{S2} = \frac{\alpha v_2}{4}$

Superscript S_i denotes the Search Engine Advertising case in which firm i acquires the top link.

Proposition 2.3. *The high-quality firm wins the auction for the top link except when advertising effectiveness is moderate and quality differentiation is small. Specifically, firm 2 wins the auction for $\overline{\alpha} < \alpha < \overline{\overline{\alpha}}$ and $\frac{v_1}{v_2} < \overline{v}$ and firm 1 wins the auction otherwise.*

Per Equation (2.3), winning the bidding game is related to the value of the link for each firm. Intuitively, this value should be greater for the high-quality firm and this is indeed the case for much of the parameter space. But when advertising effectiveness is moderate and vertical differentiation is small, the low-quality firm has a greater value and is willing to bid more. To understand this, consider three cases with different levels of advertising effectiveness: high, low and moderate.

First, when advertising effectiveness is high ($\alpha > \overline{\overline{\alpha}}$), the firm that acquires the first position on the sponsored links list will grasp a large segment of consumers that only consider its product. This is extremely desirable and not surprisingly, the value of the top link for the high-quality firm is greater.

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Second, when advertising effectiveness is low ($\alpha < \overline{\alpha}$), the size of the segment that consider only one product is relatively small. One could think that, if the high-quality firm is ever going to cede the top link, it should be now as the loss of potential customers is minimal. However, if firm 1 surrenders the top link, its gain from softened price competition is also very small. When the low-quality firm has the top link, to set the optimal price, it needs to take into account two segments of consumers: the ones that only have product 2 in their consideration set (α) and the ones that consider both products ($1-\alpha$). Since $\alpha < \overline{\alpha}$, the size of the first segment is small, and firm 2 will select a price close to the benchmark case in order to stay competitive in the $1-\alpha$ sized segment. Thus, the high-quality firm's gain from reduced price competition does not cover the loss of the α sized segment and it outbids.

Third, when advertising effectiveness is moderate ($\overline{\alpha} < \alpha < \overline{\overline{\alpha}}$), the high-quality firm is more willing to cede the top link to firm 2 as doing so softens price competition substantially. Because in such a case, the size of the segment that only considers product 2 is moderate and firm 2 is better-off charging the monopoly price ($\frac{v_2}{2}$) and maximizing profit on the α sized segment instead of setting a lower price and competing in the $1-\alpha$ sized segment. Firm 1's best response to $\frac{v_2}{2}$ is to charge monopoly price ($\frac{v_1}{2}$) as well. For the high-quality firm, leaving the top link to its rival means losing a moderate amount of potential consumers. But it also brings the benefit of avoiding price competition. The importance of this benefit depends on the degree of quality differentiation between the firms. If vertical differentiation is high ($\frac{v_1}{v_2} > \overline{v}$), price competition would not be severe when the high-quality firm acquires the top link (See Figure 2.8). However, for low levels of vertical differentiation ($\frac{v_1}{v_2} < \overline{v}$), price competition is detrimental to profits if firm 1 attains the top link. Therefore, firm 1 is better-off ceding the top link to firm 2 and mitigating price competition.

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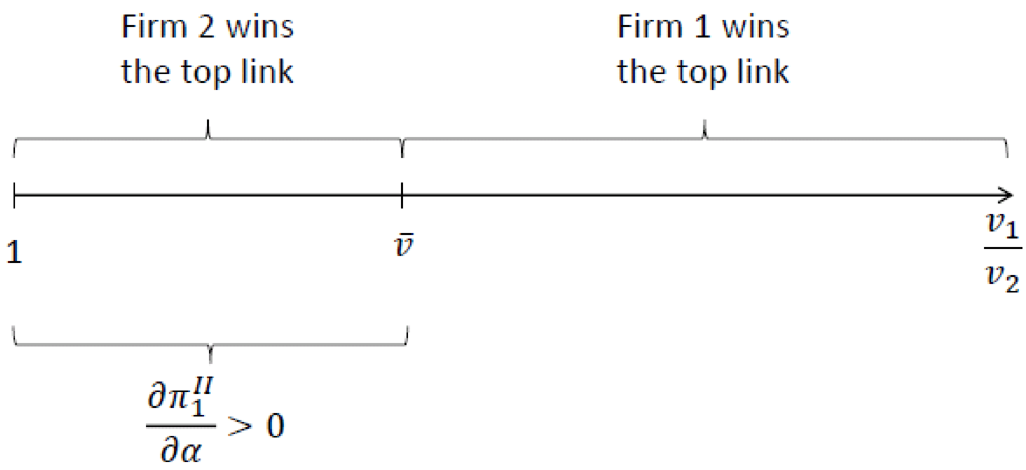

Figure 2.8: Search Engine Advertising Outcome When Advertising Effectiveness is Moderate

Proposition 2.4. *The high-quality firm's profit decreases in advertising effectiveness when advertising effectiveness is moderate and quality differentiation is small. That is* $\frac{\partial \pi_1^{S2}}{\partial \beta} < 0$ *for* $\overline{\alpha} < \alpha < \overline{\overline{\alpha}}$ *and* $\frac{v_1}{v_2} < \overline{v}$.

Proposition 2.4 states that, when advertising effectiveness is moderate and vertical differentiation is small, i.e., in the region where the high-quality firm cedes the top link to the low-quality firm per Proposition 2.3, the high-quality firm's profit decreases in advertising effectiveness. This is in contrast to the result presented in Proposition 2.2. The regions indicated in Propositions 2.2 and 2.4 are similar in the sense that in each one a firm makes a strategic advertising decision that will create an informational disparity in favor of its rival. Specifically, in display advertising model, when quality differentiation is small ($\frac{v_1}{v_2} < 1 + \frac{3(1-\beta)}{4}$), the low-quality firm foregoes free advertising. And in search advertising model, when quality differentiation is small ($\frac{v_1}{v_2} < \overline{v}$) and advertising effectiveness is moderate ($\overline{\alpha} < \alpha < \overline{\overline{\alpha}}$), the high-quality firm cedes the top sponsored link to the low-quality firm. In both of these cases,

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informational disparity in favor of the rival is advantageous because it softens price competition. This effect is continuous in the display advertising case: as β increases, firm 1 raises price and this in turn assists firm 2's profit. On the other hand, the benefit is discontinuous in the search advertising case: as α, increases firm 2 raises its price continuously until $\overline{\alpha}$, but jumps to the monopoly price ($\frac{v_2}{2}$) at $\overline{\alpha}$ eliminating price competition per Proposition 2.3. Once advertising effectiveness reaches $\overline{\alpha}$, any further increase only results in loss of potential demand for firm 1; hence decreases firm 1's profit.

2.6 *Endogenous Quality Decisions*

Up until now we have assumed exogenous quality levels in order to focus on Internet advertising strategies of vertically differentiated firms. In this section we will study how firms may make quality decisions for their products anticipating the competitive interaction in the online world. Because changing product quality usually requires long design procedures and set up time for new production processes firms cannot change their product's quality quickly. In order to incorporate this into the model we will add an initial stage in which firms make quality decisions and then compete through online advertising and price decisions in the latter stages. We will review the benchmark case followed by the analysis of each online advertising outlet.

Shaked and Sutton (1982) build a simple model that has costless quality improvement and a maximum feasible quality level. One of the firms (the "leader") chooses this upper limit; without loss of generality index this firm 1 and thus denote the upper limit v_1. They find that even if the cost of improving quality is zero, the second firm (the "follower") will not choose the maximum level. In equilibrium, firm 2 will select $v_2^* = \frac{4v_1}{7}$ and thus maintain considerable differentiation between the products

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in order to minimize the negative effect of price competition on its profit. Note that in their model consumers are automatically aware of the products in the marketplace. We will consider the cases in which firms need to employ online advertising in order to inform consumers. We start with display advertising model, assuming that the cost of running a display campaign is $C > 0$.

Proposition 2.5. *In the display advertising case, the follower will choose* $v_2^{D*} = \frac{4v_1}{7-3\beta}$ *and will not advertise.*

It is easy to see from Proposition 2.5 that the differentiation between the products is lower when the firms use display advertising ($v_2^* < v_2^{D*} < v_1$). In addition, the second firm chooses not to advertise, thus does not incur the cost of advertising. Intuitively, firm 2 is substituting informational differentiation (by not advertising) instead of quality differentiation. The outcome in the search advertising case critically depends on advertising effectiveness.

Proposition 2.6. *In the search advertising case;*

- *If advertising effectiveness is low, the follower will chose* $v_2^{S*} = \frac{2v_1}{3-\alpha}$ *and the leader will acquire the top spot.*
- *If advertising effectiveness is high, the follower will chose* $v_2^{S*} = v_1$ *and acquire the top spot.*

Comparing Propositions 2.5 and 2.6 we see that quality differentiation will always be lower in the search advertising case than the display advertising case ($v_2^{D*} < v_2^{S*} \leq v_1$). This is because of the fast nature of the auctions in the search engine case, that allows the firm who gets the top link to effectively commit to its price. Consequently, the competitive pressure declines and the firms do not need to maintain a differentiation as high as in the display case. The winner of the bidding is contingent on search

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engine advertising effectiveness. If α is low the leader firm will not cede the top link because in such a case the follower will compete in both markets. However if α is high, leaving the top link to the follower will induce it to charge the monopoly price and this will enable the leader to also charge the monopoly price; thus, eliminate price competition.[11]

2.7 *Conclusion*

In this essay, we analyzed the strategic decisions of two vertically differentiated firms that wish to promote their products online utilizing display or search engine advertising. Our study yielded a number of important managerial insights.

We have shown that informational disparity in both formats of online advertising can be an effective tool for reducing price competition, especially when quality differentiation is small. In the case of display advertising, a firm may even forego free advertising and leave a number of consumers uninformed about its product in order to soften price competition. Because it makes a smaller margin, lost demand is less important to the low-quality firm, and it will choose not to advertise when vertical differentiation between the goods is small. In such a case, an increase in advertising effectiveness increases the level of informational disparity and raises the profit of the low-quality firm that does not advertise.

Winning the top sponsored link in a search engine can also create favorable informational disparity for a firm. The bidding process ensures that the firm with the higher valuation for the top link will win. Not surprisingly, the high-quality firm bids more for a large range of parameter space. Nevertheless, we find that when advertis-

[11] The upper threshold, $\bar{\bar{\alpha}}$, is equal to 1 for $v_1 = v_2$. Hence the "moderate" region and the "high" region in Proposition 2.4 overlap.

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ing effectiveness is moderate and vertical differentiation is small, the low-quality firm will acquire the top link. Contrary to the display advertising model, in such a case, an increase in advertising effectiveness lowers the profit of the high-quality firm that does not have the top link.

Informational disparity in the marketplace reduces quality competition in addition to softening price competition. In each of the online advertising cases firms keep a smaller differentiation than the benchmark model, in which consumers are fully informed. Price commitment mechanism arising from auctions may even eliminate differentiation in the search engine advertising case.

From a managerial standpoint, these finding have a number of implications. First, a low-quality firm may not always want to use display advertising. The gain from informational disparity may be more beneficial than the lost potential demand. If quality differentiation is small and price competition is intense, a low-quality firm should not advertise even if the cost of doing so is minimal. Second, a high-quality firm should not always bid more to acquire the top sponsored link in the search engine. If advertising effectiveness is moderate and vertical differentiation is small, the high-quality firm may want to cede the top link. In this case, the low-quality firm will price very high and skim consumers who click, enabling the high-quality firm to raise its price to those consumers that continue search. Informational disparity in the marketplace also lessens quality competition, investing in quality and providing a better value to the consumers may be a better option than advertising heavily and facing stringent competition.

We would like to acknowledge that our analysis is based on a stylized model that makes a number of simplifying assumptions. We did so in order to address the strategic online advertising decisions of firms that produce vertically differentiated goods.

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The focus has been on how informational disparity can soften price competition and how firms should strategize to take advantage of this.

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3. CONTENT QUALITY IN MEDIA MARKETS

3.1 Introduction

In 2011, Warner Bros. fired Charlie Sheen for the 9th season of the sitcom "Two and a Half Men" and hired Ashton Kutcher as his replacement for the lead role in the show. While the main reason for Charlie Sheen's dismissal was his erratic behavior, the dispute with his former bosses about his compensation was another major factor. The popular actor was getting paid almost half of the show's $4 million budget per episode (Carter, 2011). His substitute Ashton Kutcher is content with $700,000 (Corneau, 2011), however the show's ratings took a noteworthy hit recently (Johnson, 2011). In the 8th season with Charlie Sheen, Two and a Half Men was the most viewed show of the night 10 times out of a possible 16 compared to 6 times out of 20 in the 9th season. In September 2004, ABC aired the pilot episodes of "Lost" that were the most expensive in the network's history, reportedly costing between $10 and $14 million (Ryan, 2004). The décor of the pilot episode included a real Lockheed L-1011 TriStar commercial jet broken up to pieces. This was in sharp contrast to the cheap CGI (computer generated imagery) effects used in the 6th and last season to the dismay of fans, apparent in 10 million average viewers in the last season down from 18.4 million in the first (Grossberg 2004; Seidman, 2010).

These two examples from TV series industry illustrate how expensive increasing the quality (or value to the consumer) of a show can be and how this quality may

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affect the number of viewers. The situation is similar in several other media industries. In sports broadcasting hiring a colorful figure like three time NBA Finals MVP Shaquille O'Neal is more expensive than hiring Matt Harpring, former Utah Jazz role player. In newspaper publishing it is not hard to imagine that recruiting top journalists with Pulitzer Prizes will increase demand but also cost more. In comic magazine publishing outsourcing artwork to Japanese artists may be cheaper but this will be at the expense of less desirable generic drawings. A radio station may employ an ultra-popular DJ such as Howard Stern as long as they can pay half a million dollar per show (Lauria, 2010). Popular celebrities and first-rate production will cost more but it may increase the value of content to consumers, which we refer to as quality. Presumably, this increase will boost demand and consequently increase revenues from advertising and content.[1] Therefore quality is an important strategic tool for the media firm and choosing an appropriate level is crucial for profitability.

This research examines the impact of competition on media firms' quality decisions. We show that the unique structure of media industries may result in deviations from standard theory. Media firms operate in two-sided markets. In the content market they sell their product to consumers and in the advertising market they sell access to these consumers' attention to advertisers. Thus rival media firms compete not only for viewers or readers but also for advertisers.

Media firm decisions have recently gained attention in the marketing literature. One particular paper by Godes, Ofek and Sarvary (2009) investigate pricing decisions of media firms and find that media product prices may *increase* with competition. Their work assumes constant quality levels for products. This is reasonable for short

[1] In some industries such as broadcast TV and radio content is free and the firms only rely on advertising for making a profit. We consider media firms that generate revenues from content market also, e.g. cable TV stations, satellite radio stations, newspapers, magazines and subscription websites.

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term interaction, as quality is stickier than content price because of employee contracts and set up time for technical investments. However in the long run these can be changed, effectively giving the media firm another important strategic tool: content quality. Hence the media firm may utilize quality level as another lever in addition to price adjustments.

In this essay, we study the strategic the interaction between media firms when the quality decision is endogenous and focus on the following research questions.

- Does a media firm choose a higher- or lower-quality level for its product compared to what a one-sided firm chooses?
- Considering under-pricing for a given quality level and over-investment in quality, what is the net effect on media firm's content price compared to the price chosen by a one-sided firm ?
- What is the impact of competition on content price and quality?

To answer these questions, we construct a stylized model in which a media firm operates in "content" and "advertising" markets by selecting quality level and price of its content and decides the amount of advertisements to be bundled with this content. The firms incur a higher cost for improving content quality and the consumers find a higher-quality product more valuable. The analysis reveals that a two-sided firm chooses a higher quality level than a one-sided firm, whether the industry structure is a monopoly or a duopoly. In other words a media firm over-invests in quality. Furthermore, when cost of quality improvement is low, the media firm may choose a considerably higher quality for its content which may lead to a higher price compared to a one-sided firm's choice. This is in contrast to under-pricing by a media firm that cannot change its content quality. When quality is endogenous, a media firm can use

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quality and price as two levers in order to boost demand. How much each lever is going to be pulled critically depends on quality improvement costs and the optimal action may be in the reverse direction compared to a media firm that only has the price lever. Note that the media firm still under-prices for a given content quality but also over-invests in quality. The former creates a direct downward force and the latter creates an indirect upward force on price. The net effect depends on the degree of over-investment and hence the cost of improving quality. In other words, an under-priced product of higher quality (in a two-sided market) may be more expensive than a regularly priced product of regular quality (in a one-sided market).

There is a similar effect on the changes in equilibrium price with respect to advertising effectiveness and variable cost. A favorable change, i. e. an increase in advertising effectiveness or a decrease in variable cost, may increase content prices when quality is endogenous in contrast to what would happen with exogenous quality levels. Again, in these cases the indirect positive effect on price arising from over-investment in quality overcomes the under-pricing effect provided the quality improvement cost is not too great. When advertising effectiveness is high a media firm under-prices and over-invests so much that it actually loses money in the content market. As a result an increase in variable cost or the cost of quality improvement lessens the distortion and cuts losses from the content market. These results hold in the monopoly case and also in the duopoly case as long as the consumers do not perceive the products too similar

We find that, similar to a one-sided market, media firms in a duopoly choose lower quality levels than a monopolist media firm. Rivalry shrinks profits and the incentive to invest in quality. However the reduction in quality due to competition is more serious in a two-sided market because both content and advertising profits

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take a hit. This decline in quality may be immense and even overcome the media firm's tendency to increase price when faced with competition. Particularly, when the consumers perceive each product more unique the duopolist media firms would charge higher prices than a monopolist for given quality levels. But if the cost of improving quality is small, the quality level is more volatile and the decline in quality may result in lower prices.

We also show that a two-sided duopolist's profit may increase in cost of improving quality. This happens because higher improvement costs may save the two firms from a prisoner's dilemma in which they wastefully over-invest in quality.

The rest of the essay is organized as follows. Section 3.2 relates our work to existing literature. Section 3.3 is model set up. Section 3.4 solves the monopoly case and Section 3.5 analyzes duopoly case. Section 3.6 provides managerial insight and concludes. All proofs are relegated to the Appendix.

3.2 *Related Literature*

This essay examines media firms that operate in two-sided markets. See Evans and Schmalensee (2005) and Rochet and Tirole (2006) for excellent reviews of two-sided platforms. The papers that specifically focus on media markets can be roughly divided according to whether or not the content is free e.g. broadcast TV vs. cable TV models. In the case of no content pricing, differentiation of programing content (Duke, 2003), amount of advertising (Duke and Galor, 2003), over- or under provision of advertising compared to social optimum (Anderson and Coate 2005) and disutility of advertisements on consumers (Masson et al., 1990) has been considered. In our work, content price is not constrained and can be positive, thus the media firm needs to balance its income from both markets.

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In the case of positive content prices, previous literature has tackled output levels for media monopolies (Chaudri, 1998), role of asymmetric customer loyalty (Chen and Xie, 2007), role of advertising effectiveness (Ghosh and Stock, 2010), firm entry in media industries (Crampes, Haritchabalet and Jullien, 2009) and mergers between media firms (Chandra, Collard-Wexler, 2009). However these papers do not allow for any change in content. Among the limited research that considers content modifications the focus is on horizontal differentiation. For example, Kind and Stahler (2010) study market shares, and Behringer and Filistrucchi (2009) investigate political differentiation of newspapers. In contrast we focus on a vertical change in content and allow for firms to invest and improve the quality of their content.

3.3 Model Setup

Our model closely resembles Godes, Ofek and Sarvary (2009) with the critical difference being endogenous quality decisions. Media firms operate in two interrelated markets. In the content market they sell their products to consumers yielding the profit π_{co}. In the advertising market they sell consumers' attention to advertisers generating π_{ad}. Thus firm i's total profit is given by $\pi_i = \pi_{co,i} + \pi_{ad,i}$.

Each firm chooses three strategic decision variables: content price p_i, number of ads that will be bundled with content y_i, and quality (or value to the consumers) of the content v_i. We assume that a media product has a base level of quality, v_0, and define v_i as the incremental value on it. For example in the newspaper industry v_0 would be the value of standard news reports from a news agency that is usually the same in all newspapers. On the other hand, v_i may be the value added by exclusive reports and popular columnists. Without loss of generality, we normalize v_0 to 1.

In various media industries quality of the content may depend on celebrities, ac-

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Figure 3.1: Timeline of the Game

tors, journalists, reporters, artists, special effects etc. People have long-term contracts and technical changes require set up time, thus adjusting quality in the short run is usually not an option. We incorporate this in our model by requiring firms to choose quality level before price or ad quantity, which are decision variables that can easily be changed in the short run. The timeline of decisions is shown in Figure 3.1. As one could expect it is increasingly more costly to deliver greater quality. We assume convex quality costs given by $kv^2/2$, where k is the quality cost parameter.

The decision variables v_i, p_i, and y_i yield the content demand for firm i, x_i. We derive the demand functions based on a representative consumer's utility.[2] The monopoly and duopoly case demands are given below.

$$x^M = (v_0 + v^M) - dy^M - p^M \; , \tag{3.1}$$

$$x_i^D = \frac{1}{1-\gamma^2}[\left(v_0 + v_i^D\right) - dy_i^D - p_i^D - \gamma(\left(v_0 + v_j^D\right) - dy_j^D - p_j^D)], \; i,j \in \{1,2\}, \; i \neq j. \tag{3.2}$$

In these specifications, d represents disutility from each ad and γ is the degree of content substitutability within the industry. (3.1) and (3.2) imply that a media firm's demand increases in its own quality (v) and decreases in the amount of ad bundling

[2] This approach is based on work of Vives (2001) and Singh and Vives (1984) and detailed in Godes, Ofek and Sarvary (2009).

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(y), disutility from ads (d), and price (p). If the firms are competing in a duopoly, anything that has a positive (negative) effect on one firm's demand has a negative (positive) effect on the other's, scaled by substitutability (γ). We need to impose the regularity condition $0<\gamma<1$, which means that own price sensitivity is greater than cross price sensitivity.

In the advertising market we derive the indirect demand for advertising in monopoly and duopoly cases based on a representative advertiser's profit function. The monopoly and duopoly case indirect demands are given below.

$$q^M = w - y^M \,, \tag{3.3}$$

$$q_i^D = w - q_i^D - hq_j^D, \, i, j \in \{1,2\}, \; i \neq j. \tag{3.4}$$

Here q represents price per impression, in other words the willingness to pay of an advertiser for each customer that is exposed to the content. It depends on the medium's advertising effectiveness (w), the amount of ads run in the industry (y) and also the degree of media substitutability for advertising (h). Media substitutability measures the similarity between each media outlet from the advertisers' perspective. We also require the regularity condition $0<h<1$. In this specification w is the marginal benefit of a single ad to an advertiser, while h captures the decrease in the marginal benefit that the advertiser faces when running an additional ad on another outlet in the same media industry.

Finally from the demand for content and inverse demand for advertising we can derive the profit functions for each market.

$$\pi_{co,i} = (p_i - c)x_i - \frac{1}{2}kv_i^2 \,, \tag{3.5}$$

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$$\pi_{ad,i} = x_i y_i q_i. \tag{3.6}$$

Note that variable cost of production, c, brings the margin to $(p_i - c)$ per unit. For a newspaper, this could be the cost of paper. The second term in $\pi_{co,i}$ is the cost of quality, which may be the salary of actors in a TV show. The profit form the ad market, $\pi_{ad,i}$, is simply the number of impressions ($x_i y_i$, given by the multiplication of number of units sold and the number of ads in each unit) times price per impression (q_i).

3.4 *Monopoly Case*

We start with the analysis of the monopoly case. The monopolist maximizes

$$\pi^M = (p^M - c)x^M - \frac{1}{2}k(v^M)^2 + x^M y^M q^M, \tag{3.7}$$

by choosing price, number of ads and content quality. Because price and ad bundling are easier to change in the short-run we solve a two stage game in which the firm decides on quality first (See Figure 3.1). Assuming $w > d \geq 0$ ensures positive advertising amount. We also assume $k > 1/2$ in order to have quasiconcave profit functions. The model is solved by backward induction.

Proposition 3.1. *The monopolist's problem has a unique solution at:* $v^{M*} = \frac{1-c}{2k-1} + \frac{(w-d)^2}{4(2k-1)}$, $y^{M*} = \frac{w-d}{2}$ *and* $p^{M*} = \frac{k(1+c)-c}{2k-1} + \frac{(w-d)[w(1-k)-d(3k-1)]}{4(2k-1)}$.

The solution implies $x^{M*} = \frac{k(1-c)}{2k-1} + \frac{(w-d)^2}{4(2k-1)}$, which is strictly higher than what a one sided monopolist would choose: $x^* = \frac{k(1-c)}{2k-1}$. This is a fundamental characteristic of a media firm. As it can generate income also from the advertising market, the media firm has an incentive to sell more units than a non-media firm. When it

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is not possible to adjust quality, a two-sided monopolist charges less than a one-sided monopolist in order to increase demand. In our model, quality level is also an important strategic tool and Proposition 3.1 shows that a media firm would choose a strictly higher quality level than a non-media firm's optimal solution, $v^* = \frac{1-c}{2k-1}$. This over-investment in quality is robust; however the effect on the optimal price is not clear cut when quality is endogenous. The optimal price in a one-sided market would be $p^* = \frac{k(1-c)-c}{2k-1}$ and the difference between p^{M*} and p^* may be positive or negative depending on k, the cost of improving quality. A two-sided monopolist may charge a higher price than a one-sided one if $k < \frac{w+d}{w+3d}$. Even though a media firm charges a lower price for a given quality level, the increase in v creates an indirect opposing force as content price increases in quality. The total impact of these two forces on optimal price critically depends on the cost of improving quality. If k is high, it is costly to improve the quality of content and the differential quality, $\frac{(w-d)^2}{4(2k-1)}$, is small. Thus, the downward force dominates and we see the expected decrease in price. But if k is low, the two-sided monopolist produces a much higher-quality product. In such a case it can charge an even higher price than a one-sided monopolist and still enjoy a significantly greater demand. The upward force dominates this time, hence a media firm may charge a higher price than a non-media firm by boosting demand through quality improvement in the long term. Note that the condition for charging a greater price, $k < \frac{w+d}{w+3d}$, depends on advertising effectiveness and disutility from ads. As disutility, d, converges to marginal benefit from an ad, w, the profit potential of the advertising market suffers greatly, the upper limit in the condition decreases, and hence it becomes less likely to see a higher price in a two-sided market.

When k is low, any change to the system has an amplified effect on the optimal quality level, which may more than offset the expected change in price.

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Corollary 3.1. *When cost of improving quality is low, (i) content price increases in advertising effectiveness and (ii) content price decreases in variable cost of producing content.*

Note that these results are in contrast to the short term effects on price; content price always decreases in advertising effectiveness and increases in variable cost when quality is exogenous. An increase in w (advertising effectiveness) results in a greater margin in the ad market and thus makes increasing demand more attractive. If k is low, using the quality lever is cheap and the media firm elevates content quality to a level that consumers are willing to pay a higher price.

Similarly, an increase in c (marginal cost) may have an unusual effect of decreasing optimal price for low k values. A greater marginal cost leads to lower x^{M*}, π_{co}^{M*} π_{ad}^{M*}, and v^{M*}. When k is low, the decrease in profits means that the firm cannot take advantage of lower quality improvement costs and v^{M*} sharply declines resulting in a lower price as well. It may be easier to understand the intuition behind the second part considering a decrease in c. This increases the potential profit of the firm and in turn its incentive to invest in quality. When k is low the bump in quality translates into a higher price. From Proposition 3.1 and Corollary 3.1 we see that for low k, v^{M*} is more volatile and this may result in an unexpected adjustment in optimal price.

A high level of advertising effectiveness also leads to following comparative statics:

Corollary 3.2. *When advertising effectiveness is high, content profits increases in (i) variable cost and (ii) cost of improving quality.*

We know from Proposition 3.1 that a media firm chooses a higher quality than the optimal level of a non-media firm by $\frac{(w-d)^2}{4(2k-1)}$. When w is high, advertisers are willing to purchase more space at a higher price per impression. Potential profits from the ad market soar, consequently the two-sided monopolist has a greater incentive to invest

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in quality and distorts v^{M*} upward from v^* significantly. This causes the media firm a net loss in the content market as cost of quality increases exponentially. An increase in costs, c or k, decreases profits and hence results in less distortion in v^{M*}, which helps cut losses from the content market.

3.5 Duopoly Case

In the duopoly case each firm maximizes

$$\pi_i^D = (p_i^D - c)x_i^D - \frac{1}{2}k(v_i^D)^2 + x_i^D y_i^D q^D \tag{3.8}$$

taking into account the competitor's optimal action. We assume $k > \frac{8-8\gamma^2+2\gamma^4}{16-24\gamma^2+9\gamma^4-\gamma^6}$ in order to have quasiconcave profit functions. The duopolists simultaneously choose quality levels in the first stage and after observing each other's action, simultaneously choose prices and ad bundling amounts in the first stage.

Proposition 3.2. *The duopoly case has a unique symmetric equilibrium in which* $y_i^{D*} = \frac{w-d}{2+h}$, $p_i^{D*} = \frac{-2d^2(3+2h)-(2+h)^2(2(1+v_i^{D*})+c(\gamma+2))+4dw(1+h)+2w^2+\gamma\left[(w-d)(w-d(1+\gamma^2(2+h))+(1+v_i^{D*})(2+h)^2(1+\gamma^2)\right]}{(2+h)^2(\gamma^2-4)}$ *and* $v_i^{D*} = \frac{2(2-\gamma^2)\left[(w-d)^2+(2+h)^2(1-c)\right]}{(2+h)^2[2\gamma^2+k(2-\gamma)^2(1+\gamma)(2+\gamma)-4]}$.

Comparing this solution to Proposition 3.1, we see that $v_i^{D*} < v^{M*}$, a two-sided duopolist chooses a lower quality level than a two-sided monopolist. Rivalry diminishes potential revenues in the second stage and this lessens each firm's incentive to invest in quality in the first stage. The situation in a one-sided market would be similar; a duopolist chooses lower quality for its product than a monopolist. However the reduction in quality due to competition is greater in a two-sided market, $\frac{v_i^{D*}}{v^{M*}} < \frac{v_i^{**}}{v^*}$ where v_i^{**} and v^* are the duopolist's and the monopolist's optimal quality choice in a one-sided market, respectively. When faced with rivalry a media firm

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has competition in both the content and the advertising markets, which causes the media firm's total profits to take a double hit. This, in turn, reduces the incentives to improve quality of the products. The decline in quality impacts the optimal price and may even overcome the media firm's tendency to choose a greater price when there is competition.

Corollary 3.3. *When competitive intensity in the content market is low, the equilibrium content price set by the duopolist is greater than that set by a monopolist only if the cost of improving quality is high.*

For low k values, Corollary 3.3 is in contrast to the outcome for exogenous quality levels. In the exogenous case a duopolist would always charge a higher price than a monopolist when γ (content substitutability) is low. In other words a media firm will respond to additional competition by increasing its price if the two firm's content is not highly substitutable. In our model, quality is another strategic tool and a media firm in a similar situation will also respond by decreasing content quality and saving from improvement costs. When k is low, the two-sided duopolist needs to reduce v_i^{D*} substantially in order to achieve significant savings over quality costs and this gives rise to a lower price because of decreased value of content to the consumers and therefore lower willingness to pay.

We highlight key comparative statics for the duopoly model. The results in Corollaries 3.1 and 3.2 carries over to the duopoly model with the caveat that γ should not be too high. For instance, if content substitutability is mild, the downward force on price arising from competition is not overwhelming and an increase in advertising effectiveness elevates optimal quality level and in turn content price rises. Similarly, when γ is low, prices are not too low and there is still some slack to decrease price in response to an increase in variable cost.

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As one would expect, an increase in substitutability between the firms, whether from the perspective of the consumer (γ) or the advertiser (h), results in a decline in total profits which in turn results in a smaller budget for quality improvement and hence lower value of content. An increase in content substitutability also decreases the equilibrium price but it may increase ad market profits if γ is already high. If content substitutability is significant, the content market is competitive and content profits are minimal. In such a case any further increase in γ results in a sharp decline in content price which increases demand and consequently ad market profits. Intuitively, the media firm is taking a bigger hit in the content market in order to reap a healthier margin in the ad market. Normally an increase in h (media substitutability) increases equilibrium price as the firms have a lesser incentive to underprice content because of more intense competition in the ad market and lower potential ad profits. However as we mentioned, an increase in h decreases equilibrium quality and the media firms may need to decrease prices also, if the cost of quality improvement is low and quality is volatile to outside changes. The interesting result about the positive impact of the quality improvement costs on total profit in the one-sided market qualitatively carries over as we state next.

Corollary 3.4. *When content substitutability is high, the total profit of each two-sided duopolist increases in the cost of improving quality.*

In Corollary 3.2 we saw that content profits of a monopolist may increase in costs. When analyzing the duopoly model we also saw that advertising profits may increase in response to greater content substitutability. But those cases merely show shifts between the media firm's sources of income. In all of those cases total profit is decreasing because of a greater decrease in profit from the other market. The media firm is simply responding to an undesirable change in the marketplace, such as

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higher costs or greater content substitutability, by taking a bigger hit in one market in order to reap the benefits from the relatively healhtier market.

However in Corollary 3.4, total profits *increase* when k (cost of quality improvement) increases. When content substitutability is high, the media firms cannot make a decent profit in the content market. In fact, at the level of γ for which Corollary 3.4 holds $\pi_{co,i}^{D*} < 0$. That is the firms are losing money in the content market in order to make money from the ad market, and the content quality is subsidized with this revenue stream. If k increases, quality, price and demand all decrease, but amount of advertising or price per impression is unchanged— content prices "absorb" all content market shifts (Godes, Ofek and Sarvary, 2009). The decline in price and demand clearly decreases the content revenues. However, the decline in quality saves some of the quality investment spending. Note that quality costs are exponential and this can amount to significant savings. In spite of the decrease in demand, amount of advertising and price per impression is unchanged, thus advertising profits are relatively stable. The net effect on total profits is positive.

Intuitively, Corollary 3.4 is a result of a prisoner's dilemma for the firms. When their content is highly substitutable both firms choose higher content quality, which may be quite expensive. Each firm would prefer a unilateral quality reduction, but cannot do so for the fear of losing customers. As k increases though, it is more and more costly to sustain higher quality levels and each firm chooses lower quality levels, knowing that its competitor also cannot afford a high level. For example, consider 3D film technology and two prime-time TV shows that are broadcast at the same time slot.[3] Shooting 3D motion picture is quite expensive, thus even when content substitutability is high it is not worth to incur the cost of 3D shooting. If producers of

[3] For the purpose of this example assume that majority of TV's in US households are capable of 3D display.

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one of the shows decide to use 3D with the hope of increased demand and advertising profits, the other show's producers will quickly follow in order not to lose demand. Both firms would be paying for the technology without an increase in demand, thus, they do not make the investment. Now suppose 3D technology is more moderately priced. In such a case using 3D will be a dominant strategy and the firms will have to invest in it. Note that if content substitutability is low, this prisoner's dilemma may be avoided. This is because shooting in 2D while your rival is shooting in 3D will not decrease demand immensely as most of the consumer's perceive the content of the shows to be quite different from each other and will not switch.

3.6 Conclusion

In this essay, we explored the effect of competition on content quality decisions and the subsequent effect on price and profits. Our study has yielded several important insights.

We show that a media firm over-invests in quality compared to a firm in a one-sided market. This is because an increase in demand is more valuable for a media firm as it also increases advertising profits. Contrary to previous literature that assumes fixed content quality, a media firm may not always under-price its content. If the cost of improving quality is not too high the media firm elevates content quality to a level in which it can set higher prices and still enjoy higher demand. Basically, the media firm has two levers at hand: price and quality. How much each lever is going to be pulled depends on quality improvement costs. Thus, for a media firm charging a low price may not be the best strategy. The managers need to carefully consider the cost of increasing content value and the potential demand increase arising from better quality content. If quality improvement costs are low, the best strategy may be

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investing more in content value.

We acknowledge that adjusting content quality may not be possible in the short run. Thus, the optimal short-term response to a change in market variable may be different from the optimal response in the long run. For example, if advertising effectiveness increases the firm may want to immediately decrease prices in order to raise content sales and take advantage of the more profitable advertising market. However, in the long run the optimal strategy may be increasing quality, if it is not too expensive to do so.

Competition will decrease the optimal quality investment by a media firm. This is also true for a one-sided firm. But the magnitude of decrease is not the same. Since competition will be in both the content and advertising markets a monopolist media firm will take a double hit from entry in the market. Thus, the managers of a media firm should spend more to build higher barriers to entry.

We also show that profit of a two-sided duopolist's profit may increase in quality improvement costs. This is because higher costs may save the firms from a wasteful prisoner's dilemma. Thus a decrease in costs may not always be good news. If a technology gets cheaper and consumers see duopolists' content highly substitutable the firms will need to adopt the new technology and suffer from higher costs. Even worse, doing so may not result in higher content sales.

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APPENDIX

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A. APPENDIX TO CHAPTER 1

Proof of Proposition 1.1. We first solve the nonintegrated case followed by the integrated case.

The integrated firm sets prices in the last stage. Setting the first order condition of (1.1) equal to zero yields $p_I^* = \frac{\alpha\beta}{2}$. Substituting the equilibrium price from the last stage, $p_I^* = \frac{\alpha\beta}{2}$, into the (integrated) firm's profit function we get $\pi_I = \frac{\alpha\beta}{4} - \frac{1}{3}k\alpha^3 - \frac{1}{3}k\beta^3$. Solving the first order conditions with respect to α and β simultaneously we get $\alpha_I^* = \beta_I^* = \frac{1}{2^2 k}$. The two second order conditions are negative.

The nonintegrated firms choose prices in stage three. Firm A's profit function is $\pi_A = (1 - \frac{p_A + p_B}{\alpha\beta})p_A$. The first order condition of the profit function with respect to p_A yields $p_A^* = \frac{\alpha\beta - p_B^*}{2}$. Similarly, $p_B^* = \frac{\alpha\beta - p_A^*}{2}$. Solving these two functions simultaneously we get $p_A^* = p_B^* = \frac{\alpha\beta}{3}$. It is easy to show that all functions are concave and thus the solutions maximize the profits. Substituting the equilibrium prices from the third stage, $p_A^* = p_B^* = \frac{\alpha\beta}{3}$ into firm B's profit function; $\pi_B = \frac{\alpha\beta}{9} - \frac{1}{3}k\beta^3$. The first order condition with respect to β yields the best response function: $\beta^*(\alpha) = \frac{\sqrt{\alpha}}{3\sqrt{k}}$. Consequently firm A's profit function in the first stage is updated and the optimal quality level of firm A is $\alpha^* = \frac{1}{2^{2/3}3^{4/3}k}$. Substituting into $\beta^*(\alpha) = \frac{\sqrt{\alpha}}{3\sqrt{k}}$ we get $\beta^* = \frac{1}{2^{1/3}3^{5/3}k}$. The second order conditions in both stages are negative.

We can see that $\alpha^* = \frac{1}{2^{2/3}3^{4/3}k} < \alpha_I^* = \frac{1}{2^2 k}$ and $\beta^* = \frac{1}{2^{1/3}3^{5/3}k} < \beta_I^* = \frac{1}{2^2 k}$. Substituting optimal quality levels, it is also easy to see that $p_A^* + p_B^* = \frac{1}{3^4 k^2} < p_I^* = \frac{1}{2^5 k^2}$. $\square$

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Proof of Proposition 1.2. In order to find the sub-game perfect equilibrium we start with the analysis of pricing decisions in the last step and then go backward. The first order conditions of the profit functions given in (1.4) and (1.5) with respect to prices (p_A^R and p_B^R) yield: $p_A^{R*} = \frac{\alpha_R\beta_R-(1-r)p_B^{R*}}{2}$ and $p_B^{R*} = \frac{\alpha_R\beta_R-p_A^{R*}}{2}$. Solving these two simultaneously we get $p_A^{R*} = \frac{(1-r)\alpha_R\beta_R}{3-r}$ and $p_B^{R*} = \frac{\alpha_R\beta_R}{3-r}$. Next we solve firm B's quality decision. The first order condition of firm B's profits $\pi_B^R = \frac{(1-r)\alpha_R\beta_R}{(3-r)^2} - \frac{1}{3}k\beta_R^3$ with respect to its quality β_R yields; $\beta_R^*\left(\alpha_R^*\right) = \frac{\sqrt{(1-r)\alpha_R}}{(3-r)\sqrt{k}}$. Next, we solve royalty rate decision of firm A. The first order condition of firm A's profit $\pi_A^R = \frac{\sqrt{(1-r)\alpha_R^3}}{(3-r)^3\sqrt{k}} - \frac{1}{3}k\alpha_R^3$ with respect to the royalty rate r yields $r^* = \frac{3}{5}$. Finally we solve the quality decision of firm A. The first order condition of firm A's profits with respect to the quality, α_R, yields: $\alpha_R^* = \frac{5^{5/3}}{2^{13/3}3^{4/3}k}$. Substituting this into $\beta_R^*\left(\alpha_R^*\right) = \frac{\sqrt{(1-r)\alpha_R}}{(3-r)\sqrt{k}}$ we get $\beta_R^* = \frac{5^{4/3}}{2^{11/3}3^{5/3}k}$. These optimal quality levels yield equilibrium prices $p_A^{R*} = \frac{5^3}{2^9 3^4 k^2}$ and $p_B^{R*} = \frac{5^4}{2^{10}3^4k^2}$. Substituting the equilibrium prices gives the marginal consumer's valuation $\widehat{\theta}_R = \frac{5}{12}$. All of the second order conditions are met.

It is easy to show that relative to the nonintegrated case without royalty fees, firm A provides a higher-quality product as $\alpha_R^* - \alpha^* = \frac{5^{5/3}}{2^{13/3}3^{4/3}k} - \frac{1}{2^{2/3}3^{4/3}k} = \frac{5^{5/3}-2^{11/3}}{2^{13/3}3^{4/3}k} > 0$ and firm B provides a lower-quality product as $\beta_R^* - \beta^* = \frac{5^{4/3}}{2^{11/3}3^{5/3}k} - \frac{1}{2^{1/3}3^{5/3}k} = \frac{5^{4/3}-2^{10/3}}{2^{11/3}3^{5/3}k} < 0$. The quality of the composite product is also lower as $\alpha_R^*\beta_R^* - \alpha^*\beta^* = \frac{5^3}{2^8 3^3 k^2} - \frac{1}{2\times 3^3k^2} = \frac{5^3-2^7}{2^8 3^3 k^2} < 0$.

It is also easy to show that compared to the nonintegrated case without royalty fees, firm A charges a lower price as $p_A^{R*} - p_A^* = \frac{5^3}{2^9 3^4 k^2} - \frac{1}{2\times 3^4 k^2} = \frac{5^3-2^8}{2^9 3^4 k^2} < 0$ and firm B charges a higher price as $p_B^{R*} - p_B^* = \frac{5^4}{2^{10}3^4k^2} - \frac{1}{2\times 3^4k^2} = \frac{5^4-2^9}{2^{10}3^4k^2} > 0$. Finally, sales under a royalty structure (cover $\frac{7}{12}$ of the market) are higher than sales of the non-integrated firms (cover $\frac{1}{3}$ of the market). □

Proof of Proposition 1.3. We start with the analysis of the competitive case. Note that

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our focus is on an equilibrium with three firms and therefore, we assume that $\alpha_L < \frac{2}{25k}$. As we show later, for higher levels of α_L, firm B deviates from the three firm equilibrium.

In order to find the sub-game equilibrium we solve the game backward starting from the last stage where the firms make their pricing decisions. We derive the first order conditions of the firms' profits (as given in 1.6, 1.7, and 1.8) with respect to the prices p_{AH}^{CR}, p_{AL}^{CR}, p_{BH}^{CR}, and p_{BL}^{CR}. This system yields the following prices: $p_{AH}^{CR*} = \frac{\alpha_H \beta\left[3(1-r)^2\alpha_H-(3-2r)\alpha_L\right]}{(1-r)[3(3-r)\alpha_H-\alpha_L]}$, $p_{AL}^{CR*} = \frac{\alpha_L\beta(\alpha_H-\alpha_L)}{3(3-r)\alpha_H-\alpha_L}$, $p_{BH}^{CR*} = \frac{\alpha_H\beta[3(1-r)\alpha_H+\alpha_L]}{(1-r)[3(3-r)\alpha_H-\alpha_L]}$, and $p_{BL}^{CR*} = \frac{\alpha_H\alpha_L\beta(4-3r)}{3(3-r)\alpha_H-\alpha_L}$. All the second conditions are negative and thus the profit functions are strictly concave in prices.

Any deviation that results in positive sales for all three firms will not improve the deviator's payoff. On the other hand, if a deviation makes one of the product pairs dominant, then one of the A firms will be driven out of the market and the demand structure given in Figure 1.2 will not be valid anymore. In such a case the firm that produce product A that remains in the market and firm B will interact as two nonintegrated complementors and the deviation may be profitable. There are four possible deviations of this kind and we analyze them below. The superscript d denotes the corresponding variables arising from the analyzed deviation.

i) Firm A_H can decrease price such that $\widehat{\theta}_H^d \leqslant \widehat{\theta}_L$ holds. (Firm A_L loses all demand.)

In order to do this A_H needs to choose $p_{AH}^d \leqslant \frac{\alpha_H\beta[(2-3r)(1-r)\alpha_H-(2-r)\alpha_L]}{(1-r)[3(3-r)\alpha_H-\alpha_L]}$. Since firm A_H's best response to p_{BH}^{CR*} is higher than this threshold value and A_H's profit is concave in p_{AH} $\left(\frac{\partial^2\pi_{AH}}{\partial p_{AH}^2} < 0\right)$; the most profitable deviation is $p_{AH}^d = \frac{\alpha_H\beta[(2-3r)(1-r)\alpha_H-(2-r)\alpha_L]}{(1-r)[3(3-r)\alpha_H-\alpha_L]}$. The resulting profit from deviation $\pi_{AH}^d = \frac{8\alpha_H^2\beta(\alpha_H-\alpha_L)}{[3(3-r)\alpha_H-\alpha_L]^2} - C(\alpha_H)$ is less than $\pi_{AH}^{CR*} = \frac{9\alpha_H^2\beta(\alpha_H-\alpha_L)}{[3(3-r)\alpha_H-\alpha_L]^2} - C(\alpha_H)$. This deviation is not profitable.

ii) Firm A_L can decrease price such that $U_H\left(p_{AH}^{CR*}, p_{BH}^{CR*}, \theta\right) \leqslant U_L\left(p_{AL}^d, p_{BL}^{CR*}, \theta\right)$

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holds for all θ. (Firm A_H loses all demand.)

Since $U_H\left(p_{AH}^{CR*}, p_{BH}^{CR*}, \theta=1\right) > U_H\left(p_{AL}=0, p_{BL}^{CR*}, \theta=1\right)$, firm A_L can never make the low quality pair the dominant choice for all consumers. In other words even if A_L decreases its price to zero, there will be some customers that strictly prefer the high quality pair. This deviation is not feasible.

iii) Firm B can increase p_{BH} to infinity and destroy $A_H B$ sales. (Firm A_H loses all demand.)

In this case deviation price is $p_{BH}^d = \frac{\alpha_H\beta[6(1-r)\alpha_H+(2-r)\alpha_L]}{2(1-r)[3(3-r)\alpha_H-\alpha_L]}$, subsequent profit from deviating is $\pi_B^d = \frac{\alpha_H\beta[6(1-r)\alpha_H+(2-r)\alpha_L]^2}{4(1-r)[3(3-r)\alpha_H-\alpha_L]^2} - C(\beta)$ and subgame equilibrium profit from not deviating is given by $\pi_B^{CR*} = \frac{\alpha_H\beta[6(1-r)\alpha_H+(2-r)\alpha_L]^2}{[3(3-r)\alpha_H-\alpha_L]^2} - C(\beta)$. In order to compare these two, we need the equilibrium royalty rate, r. Assuming the CR equilibrium holds, the equilibrium royalty rate is $r^* = \frac{27\alpha_H^2+36\alpha_H\alpha_L+\alpha_L^2}{45\alpha_H^2+15\alpha_H\alpha_L}$(See below for derivation). When we substitute r^* into the profit functions we see that $\pi_B^d < \pi_B^{CR*}$ for $\frac{\alpha_L}{\alpha_H} < 0.465$.

iv) Firm B can increase p_{BL} to infinity and destroy $A_L B$ sales. (Firm A_L loses all demand.)

In this case deviation price is $p_{BL}^d = \frac{\alpha_H\alpha_L\beta(8-3r)}{2[3(3-r)\alpha_H-\alpha_L]}$ and subsequent profit from deviating is $\pi_B^d = \frac{\alpha_H^2\alpha_L\beta(8-3r)^2}{4[3(3-r)\alpha_H-\alpha_L]^2} - C(\beta)$ is less than subgame equilibrium profit $\pi_B^{CR*} = \frac{\alpha_H^2\beta[9(1-r)\alpha_H+(7-3r)\alpha_L]}{[3(3-r)\alpha_H-\alpha_L]^2} - C(\beta)$. In order to compare these two, we need the equilibrium royalty rate, r^{CR}. Assuming the CR equilibrium holds, the equilibrium royalty rate is $r^{CR*} = \frac{27\alpha_H^2+36\alpha_H\alpha_L+\alpha_L^2}{45\alpha_H^2+15\alpha_H\alpha_L}$(See below for derivation). When we substitute r^{CR*} into the profit functions we see that $\pi_B^d < \pi_B^{CR*}$ again holds for $\frac{\alpha_L}{\alpha_H} < 0.465$.

From *iii* and *iv*, we see that if the quality differentiation is low, the equilibrium with three firms making positive sales may break down. As we will illustrate, the initial assumption ensures that $\frac{\alpha_L}{\alpha_H} < 0.465$.

Using the prices from the sub-game equilibrium, we revise firm B's profit function

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in the second stage to $\pi_B^{CR} = \frac{\alpha_H^2\beta[9(1-r)\alpha_H+(7-3r)\alpha_L]}{[3(3-r)\alpha_H-\alpha_L]^2} - \frac{1}{3}k\beta^3$. Firm B selects the profit maximizing quality level $\beta^{CR*} = \frac{\alpha_H\sqrt{9(1-r)\alpha_H+(7-3r)\alpha_L}}{\sqrt{k}[3(3-r)\alpha_H-\alpha_L]^2}$. Substituting β^{CR*} we get the high quality firm's profit function $\pi_{AH}^{CR} = \frac{9\alpha_H^3(\alpha_H-\alpha_L)\sqrt{9(1-r)\alpha_H+(7-3r)\alpha_L}}{\sqrt{k}[3(3-r)\alpha_H-\alpha_L]}$.

Next, in the first stage, the high quality firm chooses royalty rate. We differentiate π_B^{CR} with respect to r, set the first order condition to zero and find the optimal $r^{CR*} = \frac{27\alpha_H^2+36\alpha_H\alpha_L+\alpha_L^2}{45\alpha_H^2+15\alpha_H\alpha_L}$. All of the second order conditions are met. Note that this value can only be higher than $\frac{3}{5}$, the optimal r^* value with no competition. To see this, define $s \equiv \frac{\alpha_L}{\alpha_H}$ and update r^{CR*} accordingly: $r^{CR*} = \frac{27+36s+s^2}{45+15s}$. Since $s \in (0,1)$, r^{CR*} can never be less than $\frac{3}{5}$. Substituting r^{CR*}, we update the profit function to $\pi_{AH}^{CR} = \frac{25\sqrt{5}\alpha_H^{5/2}(\alpha_H-\alpha_L)(3\alpha_H+\alpha_L)^3}{24\sqrt{k}\left(18\alpha_H^2-\alpha_H\alpha_L-\alpha_L^2\right)^{5/2}} - \frac{1}{3}k\alpha_H^3$.

It turns out that characterizing a closed form solution for α_H is difficult. Instead we will first show that there is a unique pure strategy equilibrium and then derive some results regarding the characteristics of the equilibrium.

In order to ensure that equilibrium exists, we will first characterize the parameter values such that π_{AH}^{CR} is positive and then show that π_{AH}^{CR} is quasiconcave with a single peak. We define $t = \frac{\alpha_H}{\alpha_L}$ as the quality ratio between the product pairs. Since $\alpha_H > \alpha_L$, it follows that $t > 1$. $\pi_{AH}^{CR} > 0$ if and only if $\frac{25\sqrt{5}(\alpha_H-\alpha_L)(3\alpha_H+\alpha_L)^3}{8\sqrt{\alpha_H}\left(18\alpha_H^2-\alpha_H\alpha_L-\alpha_L^2\right)^{5/2}} > k^2$ holds. We divide the terms in the numerator and the denominator with appropriate powers of α_L and get $\frac{25\sqrt{5}(t-1)(3t+1)^3}{8\sqrt{t}(18t^2-t-1)^{5/2}} > k^{3/2}\alpha_L^{3/2}$. Call the function on the left-hand side of the inequality as $G_1(t)$ and the combination of parameters on the right as K. This means that $\pi_{AH}^{CR} > 0$ if $G_1(t) > K$ is satisfied. If firm A_H's choice of α_H results in a quality ratio t such that $G_1(t) > K$, firm A_H will have positive profits; hence we may have an equilibrium. We will analyze $G_1(t)$ over the region $t \in (1, \infty)$. We have $G_1(t=1) = 0$ and $\lim_{t\to\infty} G_1(t) = 0$. We also have $\frac{\partial G_1(t)}{\partial t} > 0$ for $t \in (1, 1.43)$ and $\frac{\partial G_1(t)}{\partial t} < 0$ for $t \in (1.43, \infty)$; hence $G_1(t)$ reaches maximum value $G_1(t = 1.43) = 0.054$. If $K < 0.054t$,

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for some α_H, $\pi_{AH}^{CR} > 0$ will hold and we may have an equilibrium.

Now we will study the shape of the profit function and demonstrate that it is quasiconcave. We know that: $\frac{\partial \pi_{AH}^{CR}}{\partial \alpha_H} = \frac{25\sqrt{5}\alpha_H^{3/2}(3\alpha_H+\alpha_L)^2\left(162\alpha_H^4-132\alpha_H^3\alpha_L+67\alpha_H^2\alpha_L^2+26\alpha_H\alpha_L^3+5\alpha_L^4\right)}{48\sqrt{k}\left(18\alpha_H^2-\alpha_H\alpha_L-\alpha_L^2\right)^{7/2}} - k\alpha_H^2$. When we set this first order condition equal to zero and rearrange the terms we find that $\frac{\partial \pi_{A}^{CR}}{\partial \alpha_H} = 0$ iff. $\frac{25\sqrt{5}(3\alpha_H+\alpha_L)^2\left(162\alpha_H^4-132\alpha_H^3\alpha_L+67\alpha_H^2\alpha_L^2+26\alpha_H\alpha_L^3+5\alpha_L^4\right)}{48\sqrt{\alpha_H}\left(18\alpha_H^2-\alpha_H\alpha_L-\alpha_L^2\right)^{7/2}} = k^{3/2}$ holds. We, again, divide the terms in the numerator and the denominator with appropriate powers of α_L and get $\frac{25\sqrt{5}(3t+1)^2\left(162t^4-132t^3+67t^2+26t+5\right)}{48(18t^2-t-1)^{7/2}} > k^{3/2}\alpha_L^{3/2}$. Call the function on the left-hand side of the inequality as $G_2(t)$ and note that the combination of parameters on the right is K. This means that $\frac{\partial \pi_{AH}^{CR}}{\partial \alpha_H} = 0$ if $G_1(t) = K$ is satisfied and the t value that satisfies this equality is a candidate for equilibrium. Of course, we also need to check the sign of $\frac{\partial \pi_{AH}^{CR}}{\partial \alpha_H}$ around this value. Specifically, if we have a t^* such that $\frac{\partial \pi_{AH}^{CR}}{\partial \alpha_H} > 0$, or equivalently $G_2(t^*) > K$, for $t < t^*$ and $\frac{\partial \pi_{AH}^{CR}}{\partial \alpha_H} < 0$, or equivalently $G_2(t^*) < K$, for $t > t^*$; then t^* maximizes π_{AH}^{CR} and it is the equilibrium. This is indeed the case for $K < 0.14$ as we have $G_2(t=1) = 0.14$, $\lim_{t\to\infty} G_2(t) = 0$, and $\frac{\partial G_2(t)}{\partial t} < 0$ for $t \in (1,\infty)$; hence $G_2(t)$ is a strictly and monotonically decreasing function. This means that for $K < 0.14$, there will be a single t^* that satisfies $G_2(t^*) = K$ and hence maximizes π_{AH}^{CR}. We know that $\pi_{AH}^{CR} > 0$ if $K < 0.054$. That is, if $K < 0.054$ then we have a unique equilibrium at $t^* = G_2^{-1}(K)$. In short, using the definition of t a unique equilibrium $\alpha_H^* = \alpha_L G_2^{-1}\left(k^{3/2}\alpha_L^{3/2}\right)$ exists for $K = k^{3/2}\alpha_L^{3/2} < 0.054$. Since our focus is on equilibrium with three firms we need $t^* > \frac{1}{0.465}$. This condition ensures that firm B does not want to deviate from the pricing sub-game equilibrium (See the deviation analysis at the start of the proof.) This condition is satisfied with the initial assumption $\alpha_L < \frac{2}{25k}$. □

Proof that $\pi_{AH}^{CR*} > \pi_{AH}^{R*}$. The profit of firm A_H in the competitive setting is $\pi_{AH}^{CR*} = \frac{25\sqrt{5}\alpha_H^{5/2}(\alpha_H-\alpha_L)(3\alpha_H+\alpha_L)^3}{24\sqrt{k}\left(18\alpha_H^2-\alpha_H\alpha_L-\alpha_L^2\right)^{5/2}} - \frac{1}{3}k\alpha_H^3$ and the profit of firm A in the nonintegrated case with-

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out competition is: $\pi_{AH}^{R*} = \frac{25\sqrt{5}\alpha_H^{3/2}}{864\sqrt{2}\sqrt{k}} - \frac{1}{3}k\alpha_H^3$. It is easy to see that $\pi_{AH}^{CR*}(\alpha_L = 0) = \pi_{AH}^{R*}(\alpha_L = 0)$. Thus we need to show that $\frac{d\pi_{AH}^{CR*}}{d\alpha_L} > 0$ to prove that $\pi_{AH}^{CR*} > \pi_{AH}^{R*}$.

The total derivative is $\frac{d\pi_{AH}^{CR*}}{d\alpha_L} = \frac{\partial\pi_{AH}^{CR*}}{\partial\alpha_L} + \frac{\partial\pi_{AH}^{CR*}}{\partial\alpha_H^*}\frac{d\alpha_H^*}{d\alpha_L}$, and since $\frac{\partial\pi_{AH}^{CR*}}{\partial\alpha_H^*} = 0$ the second part of the equation equals zero at the equilibrium. An inspection of the following derivative $\frac{\partial\pi_{AH}^{CR*}}{\partial\alpha_L} = \frac{25\sqrt{5}\alpha_H^{5/2}(3\alpha_H+\alpha_L)^2\left(15\alpha_H^3-124\alpha_H^2\alpha_L-17\alpha_H\alpha_L^2-2\alpha_L^3\right)}{48\sqrt{k}\left(18\alpha_H^2-\alpha_H\alpha_L-\alpha_L^2\right)^{7/2}}$ shows that all of the terms are positive with the exception of: $\left(15\alpha_H^3 - 124\alpha_H^2\alpha_L - 17\alpha_H\alpha_L^2 - 2\alpha_L^3\right)$. We can divide all the terms by α_L^3 and get $\left(15t^{*3} - 124t^{*2}\alpha_L - 17t^* - 2\right)$. This expression is positive for $t^* > 8.4$, which is satisfied for $\alpha_L < \frac{1}{50k}$, and negative otherwise. Therefore, $\frac{\partial\pi_{AH}^{CR*}}{\partial\alpha_L} > 0$ holds for $\alpha_L \in [0, \overline{\alpha}_L]$ where $\overline{\alpha}_L = \frac{1}{50k}$. It follows that there can only be one other point that satisfies $\pi_{AH}^{CR*} = \pi_{AH}^{R*}$ which is at $\alpha_L = \overline{\overline{\alpha}}_L = \frac{1}{25k}$. □

Proof that $\pi_B^{CR*} > \pi_B^{R*}$. Firm B's profit is $\pi_B^{CR*} = \frac{5\sqrt{5}\alpha_H^{3/2}(\alpha_H-\alpha_L)(3\alpha_H+\alpha_L)^3}{324\sqrt{k}\left(18\alpha_H^2-\alpha_H\alpha_L-\alpha_L^2\right)^{3/2}} - \frac{1}{3}k\beta_H^3$ in the competitive setting and $\pi_B^R = \frac{5\sqrt{5}\alpha_H^{3/2}}{648\sqrt{2}\sqrt{k}} - \frac{1}{3}k\beta_H^3$ in the nonintegrated case without competition. It is, again, easy to see that $\pi_B^{CR*}(\alpha_L = 0) = \pi_B^{R*}(\alpha_L = 0)$. Next we need to show that $\frac{d\pi_B^{CR*}}{d\alpha_L} = \frac{\partial\pi_B^{CR*}}{\partial\alpha_L} + \frac{\partial\pi_B^{CR*}}{\partial\alpha_H^*}\frac{d\alpha_H^*}{d\alpha_L} > 0$. As $\frac{\partial\pi_B^{CR*}}{\partial\alpha_L} = \frac{5\sqrt{5}\alpha_H^{5/2}(3\alpha_H+\alpha_L)^3(39\alpha_H+5a_L)}{216\sqrt{k}\left(18\alpha_H^2-\alpha_H\alpha_L-\alpha_L^2\right)^{3/2}} > 0$ and $\frac{\partial\pi_B^{CR*}}{\partial\alpha_H} = \frac{5\sqrt{5}\alpha_H^{1/2}(3\alpha_H+\alpha_L)^2\left[54\alpha_H^3-24\alpha_H^2\alpha_L-9\alpha_H\alpha_L^2-\alpha_L^3\right]}{216\sqrt{k}\left(18\alpha_H^2-\alpha_H\alpha_L-\alpha_L^2\right)^{3/2}} > 0$, we only need to show that $\frac{d\alpha_H^*}{d\alpha_L} > 0$. Using the envelope theorem this is equivalent to showing that $\frac{d\pi_{AH}^{CR*}}{d\alpha_L}$, which was proven above. Hence $\frac{d\pi_B^{CR*}}{d\alpha_L} > 0$ and $\pi_B^{CR*} > \pi_B^{R*}$. □

Proofs of consumer surplus and social welfare results. First we show that the demand for product A_H under competition is higher than the demand for A without competition. The demand for A_H under competition is $D_{AH}^{CR} = \frac{3\alpha_H}{3(3-r^{CR})\alpha_H-\alpha_L}$,and the demand for A without competition is $D_A^R = \frac{1}{3-r}$. We have $D_{AH}^{CR}(\alpha_H, r^*, \alpha_L = 0) = D_A^{R*}$. Since $r^{CR*} > r^*$ (See proof of Proposition 1.4), $D_{AH}^{CR}\left(\alpha_H, r^{CR*}, \alpha_L = 0\right) > D_A^{R*}$.

Now we will consider the case when $\alpha_L > 0$: From the full differential we write $D_{AH}^{CR}\left(\alpha_H, r^{CR*}, \alpha_L\right) = D_{AH}^{CR}\left(\alpha_H, r^{CR*}, \alpha_L = 0\right) + \frac{\partial D_{AH}^{CR}}{\partial\alpha_L}\alpha_L + \frac{\partial D_{AH}^{CR}}{\partial\alpha_H}\frac{\partial\alpha_H}{\partial\alpha_L}$ and that is equal

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to $D_{AH}^{CR}\left(\alpha_H, r^{CR*}, \alpha_L = 0\right) + 3\alpha_H + \alpha_L - 3\alpha_L \frac{\partial \alpha_H}{\partial \alpha_L}$. From the optimality and incentive conditions it must be that $\frac{\partial \alpha_H}{\partial \alpha_L} < \alpha_L$, and since $\alpha_H > \alpha_L$, the full differential above is positive. Therefore, $D_{AH}^{CR}\left(\alpha_H, r^{CR*}, \alpha_L\right) > D_{AH}^{CR}\left(\alpha_H, r^{CR*}, \alpha_L = 0\right) > D_A^{R*}$.

It follows directly that consumers' surplus increase under competition and as consumers' surplus and profits increase so is the social welfare. □

Proof that competition is essential for win-win-win-win. The monopolist in the A market and the B firm set prices in the last stage. The first order conditions of the profit functions given in (1.9) and (1.10) with respect to prices p_{AH}, p_{AL}, p_{BH}, and p_{BL} yield $p_{AH}^* = \frac{\alpha_H \beta(1-r)}{(3-r)}$, $p_{AL}^* = \frac{\alpha_L \beta}{(3-r)}$, $p_{BH}^* = \frac{\alpha_H \beta}{(3-r)}$, and $p_{BL}^* = \frac{\alpha_L \beta(1-r)}{(3-r)}$. The second order conditions are met, so these are the optimal prices. Substituting these for the marginal consumers' valuations, we see that $\widetilde{\theta} = \widehat{\theta}_H = \widehat{\theta}_L = \frac{(2-r)}{(3-r)}$. □

Proof of Proposition 1.4. The individual proofs are below. □

Proof that $\alpha^{CR*} > \alpha^{R*}$. When $\alpha_L = 0$ the competitive case converges to the case of royalty without competition. Thus, $\alpha^{CR*}(\alpha_L = 0) = \alpha^{R*}$. From the proof of Proposition 1.3 we know that $\frac{\partial \alpha_H}{\partial \alpha_L} > 0$ under the specified conditions, therefore $\alpha^{CR*} > \alpha^{R*}$. □

Proof that $\beta^{CR*} > \beta^{R*}$. We know that $\beta^{CR*} = \frac{\sqrt{5}\sqrt{\alpha_H}(3\alpha_H + \alpha_L)}{6\sqrt{k}\sqrt{18\alpha_H^2 - \alpha_H\alpha_L - \alpha_L^2}}$ and $\beta^{R*} = \frac{\sqrt{5}\sqrt{\alpha_H}}{6\sqrt{2k}}$. It is easy to see that $\beta^{CR*}(\alpha_L = 0) = \beta^{R*}$. Hence, $\frac{d\beta^{CR*}}{d\alpha_L} > 0$ if $\frac{\partial \alpha_H}{\partial \alpha_L} > 0$. Therefore $\beta^{CR*} > \beta^{R*}$ as long as $\frac{\partial \alpha_H}{\partial \alpha_L} > 0$. □

Proof that $q^{CR*} > q^{R*}$. Follows immediately from above. □

Proof that $r^{CR*} > r^*$. .

We know that $r^{CR*} = \frac{27\alpha_H^2 + 36\alpha_H\alpha_L + \alpha_L^2}{45\alpha_H^2 + 15\alpha_H\alpha_L}$. At $\alpha_L = 0$ we see that $r^{CR*} = r^{R*}$, and since $\frac{\partial r^{CR*}}{\partial \alpha_L} > 0$ it follows $r^{CR*} > r^*$. □

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A.1 Model Extensions and Robustness Checks

A.1.1 Simultaneous Quality Decisions

In the nonintegrated case without royalty fees, the analysis closely follows Proof of Proposition 1 with the only difference being solving for the first order conditions for quality decisions simultaneously instead of sequentially; yielding equilibrium qualities $\alpha^{S*} = \frac{1}{3^2 k}$ and $\beta^{S*} = \frac{1}{3^2 k}$, where superscript S denotes simultaneous case. Note that although the firms choose equal quality levels, their qualities are lower compared to the integrated case as $\alpha^{S*} = \frac{1}{3^2 k} < \alpha_I^* = \frac{1}{2^2 k}$ and $\beta^{S*} = \frac{1}{3^2 k} < \beta_I^* = \frac{1}{2^2 k}$.

Similarly in the nonintegrated case with royalty fees, the analysis closely follows Proof of Proposition 1. Solving the first order conditions for quality decisions simultaneously we get $\alpha_R^{S*} = \frac{5^{5/3}}{2^{11/3} 3^2 k} > \alpha^{S*} = \frac{1}{3^2 k}$ and $\beta_R^{S*} = \frac{5^{4/3}}{2^{10/3} 3^2 k} < \beta^{S*} = \frac{1}{3^2 k}$. These equilibrium qualities yield $q_R^{S*} = \frac{5^3}{2^7 3^4 k^2} < q^{S*} = \frac{1}{3^4 k^2}$, $p_A^{SR*} = \frac{5^3}{2^8 3^5 k^2} < p_A^{S*} = \frac{1}{3^5 k^2}$, $p_B^{SR*} = \frac{5^4}{2^9 3^5 k^2} > p_B^{S*} = \frac{1}{3^5 k^2}$, $\left(1 - \widehat{\theta}_R^{S*}\right) = \frac{5}{12} > \left(1 - \widehat{\theta}^{S*}\right) = \frac{1}{3}$, $\pi_A^{SR*} = \frac{5^5}{2^{10} 3^7 k^2} > \pi_A^{S*} = \frac{2}{3^7 k^2}$, and $\pi_B^{SR*} = \frac{5^4}{2^9 3^7 k^2} < \pi_B^{S*} = \frac{2}{3^7 k^2}$. Hence, all of the results presented in Proposition 1 hold in the simultaneous product development case.

We provide a numerical analysis of the competition with royalty rate case in Table A.1.

A.1.2 Asymmetric Cost Parameters

The analysis follows the proofs in the text closely. The equilibrium results with asymmetric cost parameters, k_A and k_B, are given in Table A.2. All the results hold qualitatively under this specification.

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Table A.1: Simultaneous Quality Decision Model Equilibrium Results

	Integrated	Nonintegrated		
		No Royalty	With Royalty	Competition
Quality	$\alpha_I^* = 2.5$	$\alpha^* = 1.11$	$\alpha_R^* = 1.28$	$\alpha_{CR}^* = 1.42$
	$\beta_I^* = 2.5$	$\beta^* = 1.11$	$\beta_R^* = 0.94$	$\beta_{CR}^* = 1.06$
	$q_I^* = 6.25$	$q^* = 1.23$	$q_R^* = 1.21$	$q_{CR}^* = 1.51$
Price	$p_I^* = 3.125$	$p_A^* = p_B^* = 0.41$	$p_A^{R*} = 0.2$	$p_{AH}^{CR*} = 0.004$
			$p_B^{R*} = 0.5$	$p_{BH}^{CR*} = 0.079$
Demand	$1 - \widehat{\theta}_I = 50\%$	$1 - \widehat{\theta} = 33\%$	$1 - \widehat{\theta}_R = 42\%$	$1 - \widetilde{\theta} = 46\%$
Profit		$\pi_A = 0.092$	$\pi_A^{R*} = 0.14$	$\pi_{AH}^{CR*} = 0.151$
	$\pi_I = 0.521$	$\pi_B = 0.092$	$\pi_B^{R*} = 0.056$	$\pi_B^{CR*} = 0.079$
		$\pi_A + \pi_B = 0.183$	$\pi_A^{R*} + \pi_B^{R*} = 0.195$	$\pi_A^{CR*} + \pi_B^{CR*} = 0.23$
Consumer Surplus	0.781	0.07	0.105	0.158
Social Welfare	1.302	0.253	0.3	0.388

The numerical values have been calculated assuming $k = 0.1$ and $\alpha_L = 0.25$

Producing the Complementary Good In-house

One solution to the difficulties arising from separate development of the complements would be to produce the other good in-house. This option is superior if one the firms has the technical skills to produce the other good efficiently. For example a firm that has the technology of designing and producing a left shoe also has the technology of designing and producing a right shoe. Therefore, we never see separate firms manufacturing only one of these complements. On the other hand, it is difficult to say the same for another complement pair like a processor and an operating system. Firms can typically achieve high levels of competence at developing and producing one of the goods, but if they also try to master developing and producing

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the other good they will not be as efficient.[1] For instance, if we assume firm A tries to develop product B in house, it will have a cost parameter $\widetilde{k}_B > k_B$, which determines the amount of spending for a given quality improvement. Firm A has an incentive to develop good B by itself, if its profit from doing so, $\widetilde{\pi}_A$, is higher than the profit from only producing good A.

$\widetilde{\pi}_A > \pi_A$ or $\quad \frac{1}{2^6 3 k_A \widetilde{k}_B} > \frac{1}{2^2 3^5 k_A k_B} \Rightarrow \widetilde{k}_B < 5.06 k_B$

Table A.2: Analytical Equilibrium Results with Asymmetric Cost Parameters

	Integrated	**Nonintegrated**	
		Royalty=0	**With Royalty**
Quality	$\alpha_I^* = \frac{1}{2^2 k_A^{2/3} k_B^{1/3}}$ $\beta_I^* = \frac{1}{2^2 k_A^{1/3} k_B^{2/3}}$ $q_I^* = \frac{1}{2^4 k_A k_B}$	$\alpha^* = \frac{1}{2^{2/3} 3^{4/3} k_A^{2/3} k_B^{1/3}}$ $\beta^* = \frac{1}{2^{1/3} 3^{5/3} k_A^{1/3} k_B^{2/3}}$ $q^* = \frac{1}{2 \times 3^2 k_A k_B}$	$\alpha_R^* = \frac{5^{5/3}}{2^{13/3} 3^{4/3} k_A^{2/3} k_B^{1/3}}$ $\beta_R^* = \frac{5^{4/3}}{2^{11/3} 3^{5/3} k_A^{1/3} k_B^{2/3}}$ $q_R^* = \frac{5^3}{2^8 3^3 k_A k_B}$
Price	$p_I^* = \frac{1}{2^5 k_A k_B}$	$p_A^* = p_B^* = \frac{1}{2 \times 3^4 k_A k_B}$	$p_A^{R*} = \frac{5^3}{2^9 3^4 k_A k_B}$ $p_B^{R*} = \frac{5^4}{2^{10} 3^4 k_A k_B}$
Demand	$1 - \widehat{\theta}_I = \frac{1}{2}$	$1 - \widehat{\theta} = \frac{1}{3}$	$1 - \widehat{\theta}_R = \frac{5}{12}$
Profit	$\pi_I = \frac{1}{2^6 3 k_A k_B}$	$\pi_A = \frac{1}{2^2 3^5 k^2}$ $\pi_B = \frac{1}{3^6 k_A k_B}$ $\pi_A + \pi_B = \frac{7}{2^2 3^6 k_A k_B}$	$\pi_A^{R*} = \frac{5^5}{2^{13} 3^5 k^2}$ $\pi_B^{R*} = \frac{5^4}{2^{10} 3^6 k_A k_B}$ $\pi_A^{R*} + \pi_B^{R*} = \frac{23 \times 5^4}{2^{13} 3^6 k_A k_B}$
Social Welfare	$\frac{5}{2^7 3 k_A k_B}$	$\frac{5}{2 \times 3^6 k_A k_B}$	$\frac{19 \times 5^4}{2^{12} 3^6 k_A k_B}$
Consumer Surplus	$\frac{1}{2^7 k_A k_B}$	$\frac{1}{2^2 3^5 k_A k_B}$	$\frac{5^4}{2^{13} 3^5 k_A k_B}$

[1] As an example, in the video game market Sony and Microsoft mostly depend on separate software firms for titles. Only Nintendo's game publishing subsidiary is a main source of hit games for the company's console. It is important to note that Nintendo develops games for its consoles since the 1970s.

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Thus, it is not profitable for firm A to develop product B by itself, unless its cost parameter for product B is less than 5.06 times the cost parameter of firm B, which specializes in good B. We next investigate firm A's willingness to produce good B in house when it charges royalty fees.

Conducting a similar analysis when the A firm can impose a royalty fee, shows that firm A prefers developing product B itself when its cost parameter for developing good B satisfies

$$\widetilde{k}_B < 3.32 k_B$$

Thus, compared to the original model, firm A is much less willing to produce good B when it can charge a royalty fee. Said differently, when royalty payments can be imposed, we should expect to see much more specialization in an industry whereby separate firms develop and produce each of the complementary products. For example, consider an industry in which firm A has a cost parameter for developing product B that is 4 times as big as firm B's cost for developing product B $\left(\widetilde{k}_B = 4k_B\right)$. When there are no royalties, firm A wants to develop product B in house and be an integrated firm. By contrast, if it can charge royalty fees, firm A is better-off letting firm B, who is more efficient, develop good B and then extract surplus from firm B through the royalty payments.

A.1.3 The Cost of Quality Has a Variable Component

Development and Variable Costs

In this case firms incur positive marginal costs in addition to upfront quality investment. While developing a new product R&D cost may increase quite quickly, it is reasonable to assume that variable cost rises more slowly with respect to improvements in quality. Thus, we assume that the marginal cost increases linearly with the

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product's quality and do not depend on the quantity sold. Firm A pays a manufacturing cost of $m\alpha$ for each product and firm B pays $m\beta$. We find that all of the results hold for low m. We provide a numerical analysis in Table A.3.

Table A.3: Development and Variable Cost Model Results

	Integrated	Nonintegrated		
		No Royalty	With Royalty	Competition
Quality	$\alpha_I^* = 2.4$	$\alpha^* = 1.37$	$\alpha_R^* = 1.57$	$\alpha_{CR}^* = 1.58$
	$\beta_I^* = 2.4$	$\beta^* = 1.19$	$\beta_R^* = 1.04$	$\beta_{CR}^* = 1.09$
	$q_I^* = 5.76$	$q^* = 1.64$	$q_R^* = 1.63$	$q_{CR}^* = 1.72$
Price	$p_I^* = 2.99$	$p_A^* = 0.57$	$p_A^{R*} = 0.28$	$p_{AH}^{CR*} = 0.106$
		$p_B^* = 0.56$	$p_B^{R*} = 0.73$	$p_{BH}^{CR*} = 0.901$
Demand	$1 - \widehat{\theta}_I = 48\%$	$1 - \widehat{\theta} = 30\%$	$1 - \widehat{\theta}_R = 38\%$	$1 - \widetilde{\theta} = 41\%$
Profit	$\pi_I = 0.401$	$\pi_A = 0.068$	$\pi_A^{R*} = 0.104$	$\pi_{AH}^{CR*} = 0.109$
		$\pi_B = 0.097$	$\pi_B^{R*} = 0.064$	$\pi_B^{CR*} = 0.075$
Consumer Surplus	0.665	0.077	0.118	146
Social Welfare	1.067	0.242	0.285	0.330

The numerical values have been calculated assuming $k = 0.1$ and $\alpha_L = 0.25$

Variable Cost Only

We also consider a case in which cost of quality only has a per-product component, i.e. without upfront investment. For tractability this marginal cost should be sufficiently convex and we use $\frac{1}{3}c\alpha^3$ and $\frac{1}{3}c\beta^3$. In such a specification, the nonintegrated firms, with or without a royalty structure, choose the same quality levels

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that the integrated firm chooses. Consequently, there is no value-creation problem. This is because margin functions in each model become multiples of each other with constant coefficients once optimal prices are substituted in the profit functions. This is also true for demand functions, hence the first order conditions are maximized at the same quality levels in each model. For example, in the integrated case margin is $\frac{3\alpha_i\beta i-k(\alpha_i^3-\beta_i^3)}{6}$ and demand is $\frac{3\alpha_i\beta i-k(\alpha_i^3-\beta_i^3)}{6\alpha_i\beta i}$. In the non-integrated case the values are $\frac{2}{3}$ of the integrated case; margin is $\frac{3\alpha_i\beta i-k(\alpha_i^3-\beta_i^3)}{9}$ and demand is $\frac{3\alpha_i\beta i-k(\alpha_i^3-\beta_i^3)}{9\alpha_i\beta i}$. Since we set the first order conditions to zero in order to find the optimal quality levels, constant numbers do not change the equilibrium decisions.

In the competition model, however, the high-quality A firm has an incentive to set price and the royalty rate such that the low-quality firm has no sales and the win-win-win-win result no longer holds. This is not surprising though, since nonintegrated firms already produce the integrated quality level the low-quality firm's role is not needed.

A.1.4 Non-strict Complementarity

A more general function for the quality of composite product is $q = z_1\alpha + z_2\beta + z_3\alpha\beta$. In this specification a consumer derives utility from using the two products together as well as from using each product by itself. Note that the main model analyzed in Sections 1.4 and 1.5 is a special case of this general model with $z_1 = z_2 = 0$. The general case also nests the nonessential complement case in which $q = z_1\alpha + z_3\alpha\beta$ (see Chen and Nalebuff 2006). We analyze the model with the more general utility function and find that our results continue to hold as long as there is sufficient complementarity, i.e. z_3 is sufficiently large compared to z_1 and z_2. A numerical analysis is given in Table A.4.

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Table A.4: Non-Strict Complementarity Model Results

	Integrated	Nonintegrated		
		No Royalty	With Royalty	Competition
Quality	$\alpha_I^* = 7.82$	$\alpha^* = 4.63$	$\alpha_R^* = 5.35$	$\alpha_{CR}^* = 5.38$
	$\beta_I^* = 7.82$	$\beta^* = 4.07$	$\beta_R^* = 3.36$	$\beta_{CR}^* = 3.49$
	$q_I^* = 199.1$	$q^* = 65.2$	$q_R^* = 62.6$	$q_{CR}^* = 65.2$
Price	$p_I^* = 99.54$	$p_A^* = 21.74$	$p_A^{R*} = 9.82$	$p_{AH}^{CR*} = 4.15$
		$p_B^* = 21.74$	$p_B^{R*} = 26.3$	$p_{BH}^{CR*} = 31.52$
Demand	$1 - \widehat{\theta}_I = 50\%$	$1 - \widehat{\theta} = 33\%$	$1 - \widehat{\theta}_R = 42\%$	$1 - \widetilde{\theta} = 44\%$
Profit	$\pi_I = 17.89$	$\pi_A = 3.94$	$\pi_A^{R*} = 6.02$	$\pi_{AH}^{CR*} = 6.12$
		$\pi_B = 5.00$	$\pi_B^{R*} = 2.88$	$\pi_B^{CR*} = 3.18$
Consumer Surplus	24.89	3.58	5.56	6.50
Social Welfare	42.78	12.52	14.46	15.80

The numerical values have been calculated assuming $k = 0.1$, $z_1 = z_2 = 1$, $z_3 = 3$ and $\alpha_L = 0.25$

A.1.5 Enriching the Competitive Setup

Firm B Offers Two Versions of Its Product

Firm B produces two versions of its product, B_H and B_L, that are exclusively compatible with A_H and A_L respectively. Consequently the two product pairs available to consumers are $A_H B_H$ and $A_L B_L$. The qualities of the B products are denoted β_H and β_L, where $\beta_H = \gamma \beta_L$ for $\gamma \in (0, 1]$. γ is a parameter that captures a possible downgrading of the B product due to compatibility reasons with the lower quality A product. For instance, in the case of "universal" apps that run on both the iPad and

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the iPhone, the iPhone version needs to be scaled down to be compatible with the iPhone's lower resolution. In this case γ would be less than 1, because the iPhone version of the app offers less quality than the iPad version. On the other hand, there are "compatible" apps that also run on both iPhone and iPad, but with the same resolution. For these apps $\gamma = 1$ as the quality offered is the same for both versions. Another example follows from the video game industry. A video game title designed for a powerful console like the PS3 may need to be scaled down to run properly on a PC. In some cases the game title is launched later in the PC market in order to allow sufficient time for the average PC to become powerful enough to run the game. In both cases γ is less than 1 because playing a scaled down game or having access to the game several months later compared to the console version decreases consumer utility. We assume that the scaled-down version of the product does not require the B firm to incur further R&D investment. As a result of the need to scale-down B_L, and the fact that consumers only care about the utility they derive from the pair, the quality differentiation between product pairs $A_H B_H$ and $A_L B_L$ depends not only on the difference between the quality levels of the A products but also on γ; a lower γ results in greater product pair differentiation.

All the results continue to hold in this setting. One can define $\widetilde{\alpha}_L = \gamma\alpha_L$ and simply replace α_L with $\widetilde{\alpha}_L$ throughout the analysis to reach the equilibrium quality levels and prices. For instance, the region in Propositions 1.2 and 1.3 becomes: $\widetilde{\alpha}_L \in (0, \overline{\alpha}_L] \Rightarrow \gamma\alpha_L \in (0, \overline{\alpha}_L] \Rightarrow \alpha_L \in (0, \frac{\overline{\alpha}_L}{\gamma}]$ and consequently Figure 1.3 changes such that critical values become $\frac{\overline{\alpha}_L}{\gamma}$ and $\frac{\overline{\overline{\alpha}}_L}{\gamma}$. Note that $\widetilde{\alpha}_L < \alpha_H$ always holds as $\gamma \in (0, 1]$.

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In our work we assumed exogenous α_L. Finding an analytical expression for optimal α_L is not feasible. Instead we will present a numerical example. Note that p_{AH} decreases sharply with α_L. Actually p_{AH} becomes zero for $\alpha_L = 0.29$. Thus if $\mathbf{r}_L$ was endogenous A_L could not choose a higher value because in such a case the high-quality firm would start modifying r_H to keep A_L out of the market. For example as you can see in Table A.5, the optimal α_L is around 0.25 for $k = 0.1$.

Table A.5: Results of Competition Case with different α_L values

	RoyaltyCompetition				
	$\alpha_L = 0.05$	$\alpha_L = 0.1$	$\alpha_L = 0.15$	$\alpha_L = 0.2$	$\alpha_L = 0.25$
Quality	$\alpha_R^* = 1.68$	$\alpha_{CR}^* = 1.68$	$\alpha = 1.68$	$\alpha = 1.69$	$\alpha = 1.69$
	$\beta_R^* = 1.09$	$\beta_{CR}^* = 1.10$	$\beta = 1.12$	$\beta = 1.13$	$\beta = 1.14$
Price	$p_{AH}^{CR*} = 0.260$	$p_{AH}^{CR*} = 0.214$	$p_{AH} = 0.164$	$p_{AH} = 0.111$	$p_{AH} = 0.051$
	$p_{AL}^{CR*} = 0.007$	$p_{AL}^{CR*} = 0.015$	$p_{AL} = 0.022$	$p_{AL} = 0.029$	$p_{AL} = 0.036$
	$p_{BH}^{CR*} = 0.793$	$p_{BH}^{CR*} = 0.834$	$p_{BH} = 0.877$	$p_{BH} = 0.933$	$p_{BH} = 0.985$
	$p_{BL}^{CR*} = 0.016$	$p_{BL}^{CR*} = 0.033$	$p_{BL} = 0.049$	$p_{BL} = 0.066$	$p_{BL} = 0.082$
Demand	$D_H = 42\%$	$D_H = 43\%$	$D_H = 43\%$	$D_H = 44\%$	$D_H = 44\%$
	$D_L = 14\%$	$D_L = 14\%$	$D_L = 14\%$	$D_L = 15\%$	$D_L = 15\%$
Royalty	$r_H^* = 0.62$	$r_H^* = 0.64$	$r_H = 0.65$	$r_H = 0.67$	$r_H = 0.69$
	$\pi_{AH}^{CR*} = 0.158$	$\pi_{AH}^{CR*} = 0.159$	$\pi_{AH}^{CR} = 0.160$	$\pi_{AH}^{CR} = 0.160$	$\pi_{AH}^{CR} = 0.160$
Profit	$\pi_B^{CR*} = 0.087$	$\pi_B^{CR*} = 0.090$	$\pi_B^{CR} = 0.092$	$\pi_B^{CR} = 0.096$	$\pi_B^{CR} = 0.100$
	$\pi_{AL}^{CR*} = 0.001$	$\pi_{AL}^{CR*} = 0.002$	$\pi_{AL}^{CR*} = 0.003$	$\pi_{AL}^{CR*} = 0.004$	$\pi_{AL}^{CR*} = 0.005$

The numerical values have been calculated assuming $k = 0.1$

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The Low-quality Firm Also Charges Royalties

We consider a scenario in which the low-quality firm also charges a royalty fee. Denote r_i as the royalty rate charged by firm A_i. For simplicity we assume that r_L is exogenous. This would mirror a situation where there is an established platform with a set quality level and royalty rate and a new and higher-quality platform enters the market. The profit functions in (1.7), (1.8), and (1.9) become

$$\pi_{AH}^{CR} = \left(1 - \widetilde{\theta}\right)\left(p_{AH} + r_H p_{BH}\right) - \frac{1}{3} k \alpha_H^3, \tag{A.1}$$

$$\pi_{AL}^{CR} = \left(\widetilde{\theta} - \widehat{\theta}_L\right)\left(p_{AL} + r_L p_{BL}\right) - \frac{1}{3} k \alpha_L^3, \text{ and} \tag{A.2}$$

$$\pi_{B}^{CR} = \left(1 - \widetilde{\theta}\right)\left(1 - r_H\right) p_{BH} + \left(\widetilde{\theta} - \widehat{\theta}_L\right)\left(1 - r_L\right) p_{BL} - \frac{1}{3} k \beta^3. \tag{A.3}$$

The analysis closely follows Proof of Proposition 1.3; hence some details will be omitted. In order to find the sub-game equilibrium we start from the last stage where the firms make their pricing decisions. We derive the first order conditions of the firms' profits (given in A.1, A.2, and A.3) with respect to the prices p_{AH}^{CR}, p_{AL}^{CR}, p_{BH}^{CR}, and p_{BL}^{CR}. This system yields the following prices: $p_{AH}^{CR*} = \frac{\alpha_H \beta\left[(1-r_H)^2(3-r_L)\alpha_H - (3-2r_H-r_L)\alpha_L\right]}{(1-r_H)[(3-r_H)(3-r_L)\alpha_H - \alpha_L]}$, $p_{AL}^{CR*} = \frac{\alpha_L \beta\left[\left((2-r_H)r_L^2 - (5-3r_H)r_L + 1\alpha_H\right) - (1-r_L)\alpha_L\right]}{(1-r_L)[(3-r_H)(3-r_L)\alpha_H - \alpha_L]}$, $p_{BH}^{CR*} = \frac{\alpha_H \beta[(1-r_H)(3-r_L)\alpha_H + (1-r_L)\alpha_L]}{(1-r_H)[(3-r_H)(3-r_L)\alpha_H - \alpha_L]}$, and $p_{BL}^{CR*} = \frac{\alpha_H \alpha_L \beta(4-3r_H-2r_L+r_H r_L)}{(1-r_L)[(3-r_H)(3-r_L)\alpha_H - \alpha_L]}$. All the second conditions are negative and thus the profit functions are strictly concave in prices.

Using the prices from the sub-game equilibrium, we revise firm B's profit function in the second stage to $\pi_B^{CR} = \frac{\alpha_H^2 \beta\left[(1-r_H)(3-r_L)^2\alpha_H + \left(7-(3-r_L)r_H - 6r_L + r_L^2\right)\alpha_L\right]}{[(3-r_H)(3-r_L)\alpha_H - \alpha_L]^2} - \frac{1}{3}k\beta^3$. Firm B selects the profit maximizing quality level $\beta^{CR*} = \frac{\alpha_H \sqrt{(1-r_H)(3-r_L)^2\alpha_H + \left(7-(3-r_L)r_H - 6r_L + r_L^2\right)\alpha_L}}{\sqrt{k}[(3-r_H)(3-r_L)\alpha_H - \alpha_L]}$.

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Substituting β^{CR*} we update the high quality firm's profit function in the first stage to $\pi_{AH}^{CR} = \frac{\alpha_H^3(\alpha_H-\alpha_L)(3-r_L)^2\sqrt{(1-r_H)(3-r_L)^2\alpha_H+\left(7-(3-r_L)r_H-6r_L+r_L^2\right)\alpha_L}}{\sqrt{k}[(3-r_H)(3-r_L)\alpha_H-\alpha_L]^3} - \frac{1}{3}k\alpha_H^3$. Now we will find firm A_H's optimal royalty rate choice, r_H^*. We differentiate π_{AH}^{CR} with respect to r_H, and find the optimal $r_H^* = \frac{3(3-r_L)^2\alpha_H^2+2\left(18-17r_L+3r_L^2\right)\alpha_L}{5[(3-r_H)(3-r_L)\alpha_H-\alpha_L]}$. All of the second order conditions are met.

Our focus is the effect of having the low-quality firm charge royalty profits on our results. Thus, we will not characterize the equilibrium conditions. Instead we will show that all firms are still better-off for some values of r_L compared to the royalty case with two nonintegrated firms in the following table. From Table A.6, it is easy to see that as $\mathbf{r}_L$ increases, p_{AL} decreases sharply reaching to nearly zero at $r_L = 0.35$. Thus if $\mathbf{r}_L$ was endogenous A_L could not choose a higher value.

Table A.6: Results of Competition Case with different r_L values

	Royalty	**Competition**				
		$\mathbf{r}_L = \mathbf{0}$	$\mathbf{r}_L = \mathbf{0.1}$	$\mathbf{r}_L = \mathbf{0.2}$	$\mathbf{r}_L = \mathbf{0.3}$	$\mathbf{r}_L = \mathbf{0.35}$
Quality	$\alpha_R^* = 1.68$	$\alpha_{CR}^* = 1.69$	$\alpha = 1.69$	$\alpha = 1.69$	$\alpha = 1.69$	$\alpha = 1.69$
	$\beta_R^* = 1.08$	$\beta_{CR}^* = 1.14$	$\beta = 1.14$	$\beta = 1.14$	$\beta = 1.14$	$\beta = 1.14$
Price	$p_A^{R*} = 0.30$	$p_{AH}^{CR*} = 0.051$	$p_{AH} = 0.057$	$p_{AH} = 0.074$	$p_{AH} = 0.087$	$p_{AH} = 0.094$
		$p_{AL}^{CR*} = 0.036$	$p_{AL} = 0.032$	$p_{AL} = 0.019$	$p_{AL} = 0.008$	$p_{AL} = 0.001$
	$p_B^{R*} = 0.75$	$p_{BH}^{CR*} = 0.985$	$p_{BH} = 0.979$	$p_{BH} = 0.961$	$p_{BH} = 0.948$	$p_{BH} = 0.941$
		$p_{BL}^{CR*} = 0.082$	$p_{BL} = 0.085$	$p_{BL} = 0.095$	$p_{BL} = 1.05$	$p_{BL} = 1.12$
Demand	$D_H = 42\%$	$D_H = 46\%$	$D_H = 44\%$	$D_H = 44\%$	$D_H = 44\%$	$D_H = 44\%$
		$D_L = 13\%$	$D_L = 15\%$	$D_L = 16\%$	$D_L = 16\%$	$D_L = 17\%$
Royalty		$r_H^* = 0.69$	$r_H = 0.68$	$r_H = 0.67$	$r_H = 0.67$	$r_H = 0.67$
Profit	$\pi_A^{R*} = 0.157$	$\pi_{AH}^{CR*} = 0.160$	$\pi_{AH}^{CR} = 0.159$	$\pi_{AH}^{CR} = 0.158$	$\pi_{AH}^{CR} = 0.157$	$\pi_{AH}^{CR} = 0.157$
	$\pi_B^{R*} = 0.084$	$\pi_B^{CR*} = 0.099$	$\pi_B^{CR} = 0.099$	$\pi_B^{CR} = 0.099$	$\pi_B^{CR} = 0.100$	$\pi_B^{CR} = 0.100$

The numerical values have been calculated assuming $k = 0.1$ and $\alpha_L = 0.25$

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A.1.6 Horizontal Differentiation in the A Market

In this stage we explore the impact of horizontal differentiation in the A market instead of quality differentiation. So we assume exogenous quality level of α for each A firm. The consumers taste parameter is $t \sim U[0,1]$ and the corresponding utility from purchasing product i is $U_i = \theta\alpha\beta - p_i - p_B - tx$ where x is the distance between a consumer's ideal product and the location of firm i. Note that, even though the A firms are not differentiated in quality our specification still has θ, i.e. a consumer's taste for quality still effects her decision to buy and willingness to pay. To keep things simple, we assume two discreet quality levels β_H and β_L for the B firm. Now we are going to analyze a model in which there is a monopolist A firm located at 1/2 and a duopoly in the A market located at 0 and 1. We will characterize the conditions under which the B firm chooses the high quality level when there are two firms in the A market and how this might benefit the A firms.

Because we are interested in the impact of competition, we will concentrate on the cases in which the market is covered $(t < \alpha\beta)$. When there is a single firm in the A market the demand area consists of two adjacent trapezoids. The edge they share is located at $x = 1/2$ and it is $(1 - \widetilde{\theta})$ long where $\widetilde{\theta} = \frac{p_A + p_B}{\alpha\beta}$. The length of the shorter edges are given by $(1 - \widehat{\theta})$ where $\widehat{\theta} = \frac{2p_A + 2p_B + t}{2\alpha\beta}$. Hence both firms face the same demand $\frac{4\alpha\beta - 4p_A - 4p_B - t}{2\alpha\beta}$. From the first order conditions we find the equilibrium prices $p_A^{M*} = p_B^{M*} = \frac{4\alpha\beta - t}{12}$. The profit functions become $\pi_A^M = \frac{(4\alpha\beta - t)^2}{144\alpha\beta} - \frac{1}{3}k\alpha^3$ and $\pi_B^M = \frac{(4\alpha\beta - t)^2}{144\alpha\beta} - \frac{1}{3}k\beta^3$.

When there are two firms in the A market, the indifferent consumer along the horizontal dimension is given by $\widetilde{x} = \frac{p_B - p_{A1+t}}{2t}$. Of the consumers located at $\widetilde{x}$, the ones that have θ in excess of of $\widetilde{\theta} = \frac{p_{A1} + p_{A2} + 2p_B + t}{2\alpha\beta}$ purchase. Consumers located at $x = 0$ find product A_1 ideal for their (horizontal) taste and $(1 - \theta_1)$ of them purchase, where

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$\theta_1 = \frac{p_{A1}+p_B}{\alpha\beta}$. Similarly at $x = 1$, $(1-\theta_2)$ of consumers purchase product A_2, where $\theta_2 = \frac{p_{A2}+p_B}{\alpha\beta}$. Note that if a consumer purchases an A-type product she also buys a B product as well. The demand for A_1 and A_2 is $D_1 = \frac{(p_{A2}-p_{A1}+t)(4\alpha\beta-3p_{A1}-p_{A2}-4p_B)}{8\alpha\beta}$ and $D_1 = \frac{(p_{A1}-p_{A2}+t)(4\alpha\beta-3p_{A2}-p_{A1}-4p_B)}{8\alpha\beta}$, respectively and the demand for firm B is $D_1 + D_2$. The equilibrium prices are $p_{A1}^{D*} = p_{A2}^{D*} = \frac{4\alpha\beta+9t-\sqrt{97t^2+8t\alpha\beta+16\alpha^2\beta^2}}{8}$, $p_B^{D*} = \frac{4\alpha\beta-11t+\sqrt{97t^2+8t\alpha\beta+16\alpha^2\beta^2}}{16}$ and the corresponding profit functions are $\pi_{A1}^D = \pi_{A2}^D = \frac{t\left(5\sqrt{97t^2+8t\alpha\beta+16\alpha^2\beta^2}-4\alpha\beta-49t\right)}{64\alpha\beta} - \frac{1}{3}k\alpha^3$ and $\pi_B^D = \frac{t\left(\sqrt{97t^2+8t\alpha\beta+16\alpha^2\beta^2}+4\alpha\beta-11t\right)^2}{256\alpha\beta} - \frac{1}{3}k\beta^3$.

Define $\gamma \equiv \frac{\beta_H}{\beta_L}$. The B firm chooses β_H when there is one A firm in the market and $\beta_H = \gamma\beta_L$ when there are two A firms. $\pi_B^D(\beta_H) = \frac{t\left(\sqrt{97t^2+8t\alpha\beta_L\gamma+16\alpha^2\beta_L^2\gamma^2}+4\alpha\beta_L\gamma-11t\right)^2}{256\alpha\beta_L\gamma} - \frac{1}{3}k\beta_L^3\gamma^3 > \pi_B^M(\beta_L) = \frac{(4\alpha\beta_L-t)^2}{144\alpha\beta_L} - \frac{1}{3}k\beta_L^3$, or $k < \frac{981t^2-8\gamma t^2-296t\alpha\beta_L\gamma-128\alpha^2\beta_L^2\gamma+144\alpha^2\beta_L^2\gamma^2}{384\alpha\beta_L^4\gamma(\gamma^3-1)} + \frac{3}{128}\sqrt{\frac{11737t^4-7563t^3\alpha\beta_L\gamma+2784t^2\alpha^2\beta_L^2\gamma^2-1280t\alpha^3\beta_L^3\gamma^3+256\alpha^4\beta_L^4\gamma^4}{\alpha^2\beta_L^8\gamma^2(\gamma^3-1)^2}}$.

Now the only thing remaining is finding out how much quality differential should the available B products have so that the original firm A benefits from competition. The relevant condition is $\pi_A^D(\beta_H) = \frac{t\left(4\alpha\beta_L\gamma+49t-5\sqrt{97t^2+8t\alpha\beta_L\gamma+16\alpha^2\beta_L^2\gamma^2}\right)^2}{256\alpha\beta_L\gamma} - \frac{1}{3}k\alpha^3 > \pi_A^M(\beta_L) = \frac{(4\alpha\beta_L-t)^2}{144\alpha\beta_L} - \frac{1}{3}k\alpha^3$, or $\gamma > \frac{45}{4}\sqrt{\frac{97t^8-688t^7\alpha\beta_L+2400t^6\alpha^2\beta_L^2-11008t^5\alpha^3\beta_L^3+24832t^4\alpha^4\beta_L^4}{\left(t^4+2t^3\alpha\beta_L-1992t^2\alpha^2\beta_L^2+32t\alpha^3\beta_L^3+256\alpha^4\beta_L^4\right)^2}} - \frac{9\left(49t^4-176t^3\alpha\beta_L+784t^2\alpha^2\beta_L^2\right)}{4\left(\left(t^4+2t^3\alpha\beta_L-1992t^2\alpha^2\beta_L^2+32t\alpha^3\beta_L^3+256\alpha^4\beta_L^4\right)\right)}$. In other words as long as there is sufficient quality differential between available B designs and the cost parameter is low such that the B firm chooses the high-quality product when there are two A firms but not when there is a single A firm in the market, competition is beneficial for A firms. The consumer taste parameter, t, needs to be moderate for this result to hold. It needs to be low enough to induce price competition between the A firms in favor of firm B, but it also needs to be high enough so that the loss from price competition is confined.

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B. APPENDIX TO CHAPTER 2

Proof of Proposition 2.1. We assume $\beta < \overline{\beta}$ in order to concentrate equilibria in pure strategies and solve the model through backwards induction. If neither firm advertises, consumers are unaware of the products and trivially both firms make zero profits. This is a dominated strategy profile. On the contrary, if both firms advertise, consumers will be fully aware and this is equivalent to the benchmark case. In the last stage of the benchmark model firms set prices maximizing (2.1) and (2.2). Solving the first order conditions with respect to prices yield the subgame equilibrium prices $p_1^B = \frac{2v_1(v_1-v_2)}{4v_1-v_2}$ and $p_2^B = \frac{v_2(v_1-v_2)}{4v_1-v_2}$. These are the profit maximizing prices as the second order conditions are negative. Profits in the benchmark case follows: $\pi_1^B = \frac{4v_1^2(v_1-v_2)}{(4v_1-v_2)^2}$ and $\pi_2^B = \frac{v_1 v_2(v_1-v_2)}{(4v_1-v_2)^2}$.

Now we direct our attention to scenarios with informational disparity. First, we will analyze the case in which firm 1 is the only advertiser. The profit functions are as follows: $\pi_1^{D1} = \left[\beta\left(1-\theta_1\right) + \left(1-\beta\right)\left(1-\widehat{\theta}\right)\right] p_1$ and $\pi_2^{D1} = \left(1-\beta\right)\left(\widehat{\theta}-\theta_2\right) p_2$. Differentiating with respect to prices and setting equal to zero we get the first order conditions that yield $p_1^{D1} = \frac{2v_1(v_1-v_2)}{4v_1-v_2-3\beta v_2}$ and $p_2^{D1} = \frac{v_2(v_1-v_2)}{4v_1-v_2-3\beta v_2}$. The second order conditions are met and the subgame equilibrium profits are $\pi_1^{D1} = \frac{4v_1(v_1-v_2)(v_1-\beta v_2)}{(4v_1-v_2-3\beta v_2)^2}$ and $\pi_2^{D1} = \frac{v_1 v_2(v_1-v_2)(1-\beta)}{(4v_1-v_2-3\beta v_2)^2}$. Deviations from this profile are not profitable for either firm. Second, we consider the case in which firm 2 is the only advertiser. The profit functions are: $\pi_1^{D2} = \left(1-\beta\right)\left(1-\widehat{\theta}\right) p_1$ and $\pi_2^{D2} = \left[\beta\left(1-\theta_2\right) + \left(1-\beta\right)\left(\widehat{\theta}-\theta_2\right)\right] p_2$. Solving the first order conditions gives $p_1^{D2} = \frac{(v_1-v_2)(2v_1-\beta v_2)}{4v_1-v_2-3\beta v_2}$ and $p_2^{D2} = \frac{v_2(v_1-v_2)(1+\beta)}{4v_1-v_2-3\beta v_2}$.

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The second order conditions are met and the profits become $\pi_1^{D2} = \frac{(v_1-v_2)(2v_1-\beta v_2)^2(1-\beta)}{(4v_1-v_2-3\beta v_2)^2}$ and $\pi_2^{D2} = \frac{v_2(v_1-v_2)(v_1-\beta v_2)(1+\beta)}{(4v_1-v_2-3\beta v_2)^2}$. Note that this profile assumes that firm 2 has positive demand from both segments, hence $\theta_2^{D2} = \frac{p_2^{D2}}{v_2} < \theta_1^{D2} = \frac{p_1^{D2}}{v_1}$ which holds for $\beta < \frac{v_1}{v_1+v_2} < \overline{\beta}$. When firm 2 is the only advertiser, we also need to take into account firm 2's option to deviate, increase price and only sell in the β sized segment. In that case firm 2 is a de facto monopoly in this segment as these consumers have only product 2 in their consideration set. Therefore firm 2's profit maximizing price would be the monopoly price $p_2^M = \frac{v_2}{2}$ yielding $\pi_2^{D1M} = \frac{\beta v_2}{4}$. This would be more profitable than charging the competitive price p_2^{D2} in the region that satisfies $\pi_2^{D1M} = \frac{\beta v_2}{4} > \pi_2^{D2} = \frac{v_2(v_1-v_2)(v_1-\beta v_2)(1+\beta)}{(4v_1-v_2-3\beta v_2)^2}$; that is, for $\beta > \overline{\beta} = \frac{4v_1^2+8v_1v_2-3v_2^2-(2v_1+v_2)\sqrt{4v_1^2-4v_1v_2+9v_2^2}}{2v_2(4v_1+5v_2)}$. Nevertheless, a candidate equilibrium profile in which firm 2 charges monopoly price is not a stable. Firm 1's best response price to p_2^M is $BR_1\left(p_2^M\right) = p_1^M$, firm 2's best response price to p_1^M is $BR_2\left(p_1^M\right) = p_2^{'}$, $BR_1\left(p_2^{'}\right) = p_1^{'}$, and finally $BR_2\left(p_1^{'}\right) = p_2^M$ completing the full circle.

Comparing the subgame equilibrium profits, we see that $\pi_1^{D1} = \frac{4v_1(v_1-v_2)(v_1-\beta v_2)}{(4v_1-v_2-3\beta v_2)^2} > \pi_1^B = \frac{4v_1^2(v_1-v_2)}{(4v_1-v_2)^2} > \pi_1^{D2} = \frac{(v_1-v_2)(2v_1-\beta v_2)^2(1-\beta)}{(4v_1-v_2-3\beta v_2)^2}$. Thus, advertising is a dominant strategy for the high-quality firm. Hence, for the low-quality firm we only need to compare the cases in which firm 1 advertises. It is also easy to see that $\pi_2^B = \frac{v_1v_2(v_1-v_2)}{(4v_1-v_2)^2} > \pi_2^{D1} = \frac{v_1v_2(v_1-v_2)(1-\beta)}{(4v_1-v_2-3\beta v_2)^2}$ is satisfied for $\frac{v_1}{v_2} \geqslant 1 + \frac{3\sqrt{1-\beta}}{4}$. The low-quality firm will advertise only when there is sufficient quality differentiation. □

Proof of Proposition 2.2. The derivative of firm 2's profits when firm 1 is the display advertiser with respect to advertising effectiveness is $\frac{\partial \pi_2^{D1}}{\partial \beta} = \frac{v_1v_2(v_1-v_2)[(7-3\beta)v_2-4v_1]}{(4v_1-v_2-3\beta v_2)^3}$. An inspection of this expression shows that $\frac{\partial \pi_2^{D1}}{\partial \beta} > 0$ for $\frac{v_1}{v_2} < 1 + \frac{3(1-\beta)}{4}$. □

Proof of Proposition 2.3. Suppose the high-quality firm attains the top link. In the

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second stage firm 2 maximizes $\pi_2^{S1} = (1-\alpha)\left(\widehat{\theta}-\theta_2\right)p_2$. The optimal price is $p_2^{S1} = \frac{p_1^{S1}v_2}{2v_1}$. Substituting the subgame equilibrium price, firm 1's profit function in the first stage is updated to $\pi_1^{S1} = \left[\alpha\left(1-\theta_1\right)+(1-\alpha)\left(1-\frac{p_1-p_2^{S1}}{v_1-v_2}\right)\right]p_1$. The first order condition yields $p_1^{S1} = \frac{v_1(v_1-v_2)}{2v_1-v_2-\alpha v_2}$. Substituting p_1^{S1} we get $p_2^{S1} = \frac{v_2(v_1-v_2)}{2(2v_1-v_2-\alpha v_2)}$, $\pi_1^{S1} = \frac{v_1(v_1-v_2)}{2(2v_1-v_2-\alpha v_2)}$ and $\pi_2^{S1} = \frac{v_1v_2(v_1-v_2)(1-\alpha)}{4(2v_1-v_2-\alpha v_2)^2}$. The second order conditions are met.

We next analyze the case in which the low-quality firm acquires the top link. The low-quality firm has two options. It can charge a competitive price, p_2^C, such that $\theta_2 < \theta_1$ and get demand from both segments, or it can charge the monopoly price, $p_2^M = \frac{v_2}{2}$, and maximize profits from the α sized segment. In this second scenario, the high-quality firms best response is $p_1^M = \frac{v_1}{2}$ in the second stage yielding profits $\pi_1^{S2M} = \frac{(1-\alpha)v_1}{4}$ and $\pi_2^{S2M} = \frac{\alpha v_2}{4}$. Note that since price is sticky in the search advertising model, the firm that has the top link cannot change price in the second stage. Also note that at these prices $\theta_2 = \theta_1$ and hence firm 2 gets no demand from the $1-\alpha$ sized market.

The low-quality firm's other option is charging a lower price and securing positive sales from both segments. Assuming $\theta_2 < \theta_1$, firm 1 maximizes $\pi_1^{S2} = (1-\alpha)\left(1-\widehat{\theta}\right)p_1$ in the second stage. Solving the first order condition gives $p_1^{S2} = \frac{p_2^{S2}+v_1+v_2}{2}$. The low-quality firm's profit function becomes $\pi_2^{D2} = \left[\alpha\left(1-\theta_2\right)+(1-\alpha)\left(\frac{p_1^{S2}-p_2}{v_1-v_2}-\theta_2\right)\right]p_2$. Differentiating with respect to p_2 and solving yields $p_2^{S2C} = \frac{v_2(v_1-v_2)(1+\alpha)}{2(2v_1-v_2-\alpha v_2)}$. Substituting this price we get $p_1^{S2C} = \frac{(v_1-v_2)(4v_1-v_2+\alpha v_2)}{4(2v_1-v_2-\alpha v_2)}$, $\pi_1^{S2C} = \frac{(v_1-v_2)(4v_1-v_2+\alpha v_2)^2(1-\alpha)}{16(2v_1-v_2-\alpha v_2)^2}$ and $\pi_2^{S2C} = \frac{v_2(v_1-v_2)(1+\alpha)^2}{8(2v_1-v_2-\alpha v_2)}$.

When we compare these two options, it is easy to see that firm 2 charges monopoly price if $\pi_2^{S2M} = \frac{\alpha v_2}{4} > \pi_2^{S2C} = \frac{v_2(v_1-v_2)(1+\alpha)^2}{8(2v_1-v_2-\alpha v_2)}$. Simplifying this inequality we conclude that firm 2 charges monopoly price for $\alpha > \overline{\alpha} = \frac{v_1-v_2}{v_1+v_2}$.

Now in order to find the winner of the auction we need to compare the sub-

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game equilibrium industry profits per Equation (2.4). First consider the case when advertising effectiveness is low $\alpha < \overline{\alpha}$. If firm 2 attains the top link it will set the competitive price. Using algebra, it is easy to see that $\pi_1^{S1} = \frac{v_1(v_1-v_2)}{2(2v_1-v_2-\alpha v_2)} + \pi_2^{S1} = \frac{v_1v_2(v_1-v_2)(1-\alpha)}{4(2v_1-v_2-\alpha v_2)^2} > \pi_1^{S2C} = \frac{(v_1-v_2)(4v_1-v_2+\alpha v_2)^2(1-\alpha)}{16(2v_1-v_2-\alpha v_2)^2} + \pi_2^{S2C} = \frac{v_2(v_1-v_2)(1+\alpha)^2}{8(2v_1-v_2-\alpha v_2)}$ for $\alpha < \overline{\alpha}$. Thus, for low advertising effectiveness firm 1 acquires the top link. We now consider higher advertising effectiveness $\alpha > \overline{\alpha}$, that induces the low-quality firm to charge the monopoly price. Comparing $\pi_1^{S1} = \frac{v_1(v_1-v_2)}{2(2v_1-v_2-\alpha v_2)} + \pi_2^{S1} = \frac{v_1v_2(v_1-v_2)(1-\alpha)}{4(2v_1-v_2-\alpha v_2)^2}$ and $\pi_1^{S2M} = \frac{(1-\alpha)v_1}{4} + \pi_2^{S2M} = \frac{\alpha v_2}{4}$, we conclude that firm 2 acquires the top link in the region $\overline{\alpha} < \alpha < \overline{\overline{\alpha}}$ and $\frac{v_1}{v_2} < \overline{v}$. Therefore the low-quality firm attains the top link for moderate advertising effectiveness and small quality differentiation. $\square$

Proof of Proposition 2.4. The derivative of firm 1's profits when firm 2 acquires the top link with respect to advertising effectiveness is $\frac{\partial \pi_1^{S2}}{\partial \alpha} = \frac{-v_1}{4v} < 0$. $\square$

Proof of Proposition 2.5. When only the high quality firm advertises, the derivative of firm 2's profits with respect to own quality $\frac{\partial \pi_2^{D1}}{\partial v_2} = \frac{v_1^2(1-\beta)(4v_1-v_2(7-3\beta))}{[4v_1-v_2(1+3\beta)]^3}$, which is negative for $v_2 > \frac{4v_1}{7-3\beta}$. Thus, optimal quality level for firm 2 is $v_2^{D*} = \frac{4v_1}{7-3\beta}$. The equilibrium profit in this case is equal to the equilibrium revenue when both firms advertise. However advertising is dominated because of the associated cost, C. $\square$

Proof of Proposition 2.6. When the leader has the top link, the derivative of the follower's profits with respect to own quality $\frac{\partial \pi_2^{S1}}{\partial v_2} = \frac{v_1v_2(v_1-v_2)(2v_1-v_2(3-\alpha))}{4[2v_1-v_2(1+\alpha)]^3}$, which is negative for $v_2 > \frac{2v_1}{3-\alpha}$. Thus, optimal quality level for firm 2 is $v_2^{S*} = \frac{2v_1}{3-\alpha}$. When the follower has the top link, the derivative of the follower's profits with respect to own quality $\frac{\partial \pi_2^{S2}}{\partial v_2} > 0$. Thus, optimal quality level for firm 2 is $v_2^{S*} = v_1$. The profit fuctions in each of these cases intersect at $\alpha\prime$; for $\alpha < \alpha\prime$ the low quality firm anticipates that it cannot win the bidding and chooses $v_2^{S*} = \frac{2v_1}{3-\alpha}$. $\square$

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C. APPENDIX TO CHAPTER 3

Proof of Proposition 3.1. In the second stage, the monopolist chooses p^M and y^M. Differentiating (3.7) with respect to p^M and solving for the first order conditions yields $p^{M*} = \frac{1+v^M+c-y^M(w+d-y^M)}{2}$, and the second order condition is negative. Substituting this into (3.1) we get $x^{M*} = \frac{1+v^M-c+y^M(w-d-y^M)}{2}$. Substituting this into the profit function and maximizing with respect to y^M yields three possible solutions: $y^{M*} = \frac{w-d}{2}$, $y^{M*} = \frac{w-d-\sqrt{4(1+v^M-c)+(w-d)^2}}{2}$ and $y^{M*} = \frac{w-d+\sqrt{4(1+v^M-c)+(w-d)^2}}{2}$. Straightforward algebra shows that $x^M = 0$ at the latter roots and, thus, profit is zero. At $y^{M*} = \frac{w-d}{2}$ the second order condition is met and it is indeed the optimal solution.

In the first stage, we substitute p^{M*} and y^{M*} into the profit function and maximize with respect to v^M. Differentiating the profit function and setting derivative equal to zero yields $v^{M*} = \frac{4(1-c)+(w-d)^2}{4(2k-1)}$. The second order condition is met as long as $k < 1/2$. □

Proof of Corollary 3.1. (i)$\frac{\partial p^{M*}}{\partial w} = \frac{w-k(w+d)}{2(2k-1)}$ is positive iff. $k < \frac{w}{w+d}$. (ii)$\frac{\partial p^{M*}}{\partial c} = \frac{k-1}{2k-1}$ is negative iff. $k < 1$. □

Proof of Corollary 3.2. (i)$\frac{\partial \pi_{co}^{M*}}{\partial c} = \frac{k[d(w-d)+2c-2]}{2(2k-1)}$ is positive iff. $w < \frac{2-2c+d^2}{d}$. (ii)$\frac{\partial \pi_{co}^{M*}}{\partial k} = \frac{\left[4-4c+(w-d)^2\right]\left[w^2+2wd-3d^2-4+4c\right]}{32(2k-1)^2}$. The denominator and the first term in the numerator is always positive. The second term in the numerator is quadratic and has the roots $w' = 2\sqrt{1-c+d^2} - d$ and $w'' = -2\sqrt{1-c+d^2} - d$. The comparative static is positive for $w > w'$ and $w < w''$. Since the second root is always negative and $w > 0$; $\frac{\partial \pi_{co}^{M*}}{\partial k} > 0$

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iff. $w' > 2\sqrt{1-c+d^2} - d$. $\square$

Proof of Proposition 3.2. We will start with the second stage and use backward induction. Differentiating (3.7) with respect to p_i^D and y_i^D yields the best response functions for firm i. Solving for p_i^D's simultaneously yield the unique solution as a function of y_i^D: $p_i^{D*}(y_i^D, y_j^D) = \frac{2+2v_i^D+2c-2y_i^D(w+d-y_i^D-hy_j^D)-\gamma[v_j^D+y_j^D(w-d-y_j^D-hy_i^D)+\gamma(v_i^D-dy_i^D+\gamma-c+1)+1-c]}{4-\gamma^2}$. The second order conditions are always met and we substitute p_1^{D*} and p_2^{D*} into the first order conditions for y_1^D and y_2^D. Setting equal to zero and solving for the best-response function, $y_1^{D*}(y_2^D)$, yields three possible solutions: $y_1^D = \frac{w-d-hy_2^D}{2}$, $y_1^D = \frac{w-d-hy_2^D}{2} \pm \sqrt{(w-d-hy_2^D)^2 + 4[1-c+v_1^D-\gamma(v_2^D-dy_2^D+1-p_2^{D*}(y_1^D, y_2^D))]}$. It is easy to show that $x_1^D = 0$ at the latter roots and profits are zero. Thus, the unique best-response function is $y_1^{D*}(y_2^D) = \frac{w-d-hy_2^D}{2}$. $y_2^{D*}(y_1^D)$ is a symmetric function. Solving the two simultaneously yields $y_1^D = y_2^D = \frac{w-d}{2+h}$. Revenue evaluated at these values is positive, thus, the solution is indeed a maximum.

We next solve the quality decision. Substituting p_i^{D*} and y_i^{D*} to the profit functions, differentiating with respect to appropriate v_i^{D*}, and setting the derivatives equal to zero yields $v_1^{D*} = v_2^{D*} = \frac{2(2-\gamma^2)\left[(w-d)^2+(2+h)^2(1-c)\right]}{(2+h)^2[2\gamma^2+k(2-\gamma)^2(1+\gamma)(2+\gamma)-4]}$. The second order condition is negative as long as $k > \frac{8-8\gamma^2+2\gamma^4}{16-24\gamma^2+9\gamma^4-\gamma^6}$ holds. $\square$

Proof of Corollary 3.3. Let $\Delta p \equiv p^{D*} - p^{M*}$. $\lim\limits_{\gamma \to 0} \Delta p \to \frac{h(w-d)[w(4+h)(k-1)+d(4k+h(3k-1))]}{4(2+h)^2(2k-1)}$. All the terms except the one in brackets are positive. The term in the brackets is negative iff. $k < \frac{4w+hw+hd}{4w+hw+3hd+4d}$. $\square$

Proof of Corollary 3.4. $\lim\limits_{\gamma \to 1} \frac{\partial \pi^{D*}}{\partial k} \to \frac{(3k+1)\left[(2+h)^2(1-c)+(w-d)^2\right]^2}{2(2+h)^4(3k-1)^3} > 0$. $\square$

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