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Information Goods vs. Industrial Goods: Cost Structure and Competition

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We study markets for information goods and find that they differ significantly from markets for traditional industrial goods. Markets for information goods in which products are vertically differentiated lack the segmentation inherent in markets for industrial goods. As a result, a monopoly will offer only a single product. Competition leads to highly concentrated information-good markets, with the leading firm behaving almost like a monopoly even with free entry and without network effects. We study how the structure of the firms' cost functions drives our results.

Key words: information goods; convex development cost; product and price competition
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1. Introduction

The ongoing transformation of the world economy into an information economy challenges conventional thinking in a variety of ways (see Shapiro and Varian 1999). This paper examines the impact of this transformation on the nature of quality and price competition and on the resulting market structure. We find that applying classical models to markets for information goods can lead to qualitatively different results from those obtained for traditional industrial goods.

An information good is a good whose unit production cost (including the cost of distribution) is negligible compared to its amortized development cost. Once an information good has been developed, additional units may be produced and distributed at virtually zero cost, for example, by allowing it to be downloaded over the Internet. In contrast, with industrial goods, the unit costs of production and distribution are often dominant. The best examples of information goods are digital products, including all types of computer software (operating systems, programming tools, applications, games), online services ranging from Internet search engines and portals (e.g., Google, Yahoo, MSN) to online content (e.g., Lexis/Nexis, Dow Jones, Reuters), and other forms of digital content (movies, television programming, music).

Our model is based on *vertical* differentiation. Vertical differentiation models are stylized models with a single "quality" characteristic that all consumers prefer more of, although they may vary in their willingness to pay for it. For computer software, for example, (inverse) quality may be measured by the number of defects (holding severity constant), which depends on the development effort. For a content provider, quality may reflect the depth and accuracy of the content. For a search engine, quality may reflect the ability of the search engine to find relevant results, which is increasing in its development effort.

A number of papers extend the early vertical differentiation model of Mussa and Rosen (1978) (e.g., Shaked and Sutton 1982, Bonanno 1986, Moorthy 1988). Early work examining the breadth of a firm's product line includes Shaked and Sutton (1983) and Gabszewicz et al. (1986). Table 1 summarizes the relationship between this paper and earlier work.

Another stream of research explores versioning of information goods. Bhargava and Choudhary (2001, 2008) show that the breadth of a monopoly's product line depends on the value-to-cost ratios of potential product offerings. Versioning has also been studied in other contexts, including network externalities (Jing 2003), the relationship between market segmentation and product differentiation (Wei and Nault 2009), antipiracy (Wu et al. 2003), and entry deterrence (Wei and Nault 2008).

In our model, information-good firms incur development costs that increase with product quality, but their unit costs are zero. In comparison, industrial-good firms incur no development cost but have positive unit costs that increase with product quality. We compare the equilibria of industrial-good and

Table 1 Comparison of Features of This Paper and Those of Related Literature

	Research objective	Information goods	Industrial goods	Comparative analysis	Endogenous quality choice	Development complexity
Moorthy (1988)	Product differentiation and entry deterrence		✓		✓	
Motta (1993)	Bertrand vs. Cournot product differentiation	✓	✓		✓	
Deneckere and McAfee (1996)	Damaged goods and product differentiation	✓	✓			
Economides and Flyer (1997)	Market structure for network goods[a]	✓				
Lehmann-Grube (1997)	Higher-quality firm advantage	✓			✓	
Bakos and Brynjolfsson (1999)	Bundling information goods	✓				
Dewan et al. (2000)	Distribution channels for information goods	✓				
Bhargava et al. (2001, 2008)	Versioning of product line	✓	✓			
Jing (2003)	Versioning with network externalities	✓				
Rochet and Tirole (2003)	Platform competition in two-sided markets	✓				
Sundararajan (2004)	Nonlinear pricing of information goods	✓				
Parker and Van Alstyne (2005)	Subsidies in two-sided markets	✓				
Eisenmann et al. (2006)	Strategies for two-sided markets	✓				
Wei and Nault (2008)	Versioning, sequential entry, and deterrence	✓			✓	
This paper	Information goods vs. industrial-good markets	✓	✓	✓	✓	✓

[a]Economides and Flyer (1997) study the concentration of network goods markets and its effects on prices, quantities, and welfare. Although in their analyses, the firms have zero unit costs (which corresponds to information goods in our model), this is immaterial for their analysis.

information-good markets and find that they are dramatically different. Information-good markets lack the segmentation inherent in industrial-good markets, which results in greater product differentiation, with the highest-quality firm extracting the most industry profits. In a duopoly, the leading firm chooses a quality that is very close to that of a single-product monopoly, with the other firm choosing a much lower quality and earning much smaller profits. In contrast, in industrial-good markets neither firm has the market power to select a product quality very close to that of a single-product monopoly, and the allocation of profits is more equal. Moreover, the dominance of the leading firm in information-good markets is driven by the shape of the development cost function, which reflects the complexity of the development process. Our results imply that improvements in development techniques will lead to markets that are even less competitive. In addition, although free entry leads to the welfare-maximizing outcome for industrial goods, it does not for information goods. Instead, the leading firm is not significantly affected by the entry of additional firms, and it continues to behave almost like a monopoly.

With information goods, increasing market size not only allows firms to sell more units, but also allows them to develop higher-quality products. As a result, firm profits are increasing and convex in market size even in the absence of network effects. Moreover, the rate at which profits increase is a decreasing function of the development complexity. In contrast, with industrial goods, firm profits increase linearly with market size. Finally, we find that markets for information goods are characterized by significant quality distortions, which in turn depend on the shape of the development cost function: as development processes become more scalable, the quality distortion increases.

The structure of the paper is as follows. Our model and the benchmarks of welfare maximization and monopoly are introduced in the next section. Section 3 studies a duopoly market. Section 4 contrasts markets for industrial and information goods. In §5, we consider how our results apply to the search market, the microprocessor market, and the authoring software market. We also discuss the implications of our results for technology users and vendors.

2. Model, Welfare Maximization, and Monopoly

We define an *information good* as a product whose unit production and distribution cost is zero, once it has been developed. For example, once Microsoft has developed a new software product, the cost of distributing it over the Internet is negligible. Our paper builds on classical models of vertical differentiation where all consumers prefer more of a characteristic called "quality," but they differ in their willingness to pay for it. Vertical differentiation is particularly appropriate for many types of information goods, where key characteristics such as ease of use, speed, and functionality are characteristics where, ceteris paribus, all consumers prefer more.

On the demand side, our model is similar to the one in Shaked and Sutton (1982, 1983) and a generalization of a model in Tirole (1988) and Choi and Shin (1992) (and used by Lehmann-Grube 1997). We first consider a market with a single product of quality u and unit price p, where $u > 1$ and $p > 0$.[1]

[1] As described below, the assumption $u > 1$ is made without loss of generality to facilitate the exposition.

All consumers prefer higher quality, but vary in their willingness to pay for it. Consumer types t are uniformly distributed over $[0, 1]$, and there are N potential consumers (so the market is characterized by a uniform distribution multiplied by a scale parameter N). Each consumer chooses whether or not to buy a single unit of the product. The net value of the unit for a type-t consumer is $[t \cdot u - p]$. More generally, we will consider an n-product market with qualities $u_1, u_2, \ldots, u_n$ and prices $p_1, p_2, \ldots, p_n$.

2.1. Quality Choice

Following Motta (1993), Lehman-Grube (1997), and Wei and Nault (2008), we assume a convex development cost function, which is the natural result of making the most cost-effective quality improvements first. We assume that the cost of developing an information good with quality u is $k \cdot u^\alpha$ ($k > 0$, $u > 1$, $\alpha > 1$), independent of the quantity sold, and that its unit cost is zero.[2] The coefficient k is a scale parameter, and α is a measure of the complexity of the development process.

In software development, cost estimation models (Boehm 1981, Boehm et al. 2000) typically posit a relationship of the form $C = k \cdot u^\alpha$, where C is the development cost, k is a positive constant, u is a measure of functionality, and α measures development complexity.[3] Indeed, diseconomies of scale have become a cornerstone of software engineering (see Brooks 1995, Benediktsson et al. 2003). The convexity of the development cost function is captured by the development complexity α: as α decreases, the additional expenditure required for a fixed percentage increase in quality decreases, i.e., software development becomes more scalable. For example, object-oriented programming facilitates the development of large systems through code reuse.

2.2. Welfare Maximization

We first examine the welfare-efficient solution, i.e., the quality and price choices that maximize social welfare. With information goods, the welfare-efficient price of *any* product, regardless of its quality, is zero. Thus, even if multiple information goods were developed, the efficient solution would price them at zero, resulting in all consumers choosing the highest-quality product. As a result, consumers have homogeneous ideal points for information goods. It follows that the multiproduct welfare-efficient solution is to develop a single product with $u = [N/(2 \cdot \alpha \cdot k)]^{[1/(\alpha-1)]}$, priced at zero, and the market is covered. Then, social welfare is given by $(\alpha - 1) \cdot k \cdot [N/(2 \cdot \alpha \cdot k)]^{[\alpha/(\alpha-1)]}$. Quality increases with the market size N, because amortizing the development cost over a larger market makes it efficient to develop a product of higher quality. As the market size increases, not only are more people being served, they also buy a higher-quality product, and social welfare increases with market size N as $N^{[\alpha/(\alpha-1)]}$, i.e., much faster than linearly. Clearly, this result depends on the convexity of the development cost function, i.e., $\alpha > 1$.

2.3. Monopoly

The multiproduct efficient solution for information goods is to offer a single product because consumers have homogeneous ideal points under unit cost pricing, which makes it more difficult for a monopoly to segment consumers. Proposition 1 shows that for information goods, the losses from cannibalization always outweigh the benefits of segmentation.

Proposition 1.[4] *A multiproduct monopoly will develop and sell a single information good with*

$$u = \left(\frac{N}{4 \cdot \alpha \cdot k}\right)^{1/(\alpha-1)}, \qquad p = \frac{1}{2} \cdot \left(\frac{N}{4 \cdot \alpha \cdot k}\right)^{1/(\alpha-1)},$$

$$m = \frac{N}{2}, \qquad \Pi = (\alpha - 1) \cdot k \cdot \left(\frac{N}{4 \cdot \alpha \cdot k}\right)^{\alpha/(\alpha-1)},$$

$$\textit{Consumer Surplus} = \frac{\alpha \cdot k}{2} \cdot \left(\frac{N}{4 \cdot \alpha \cdot k}\right)^{\alpha/(\alpha-1)},$$

$$\textit{Social Welfare} = \left(\frac{3 \cdot \alpha}{2} - 1\right) \cdot k \cdot \left(\frac{N}{4 \cdot \alpha \cdot k}\right)^{\alpha/(\alpha-1)}.$$

The single-product result of Proposition 1 depends on the specific assumptions of our model. Gabszewicz et al. (1986) show that if consumers positively value quality on an interval which is bounded away from zero, and the market is covered (all consumers purchase a product), then a multiproduct monopoly will offer all possible products if the range of consumer types is sufficiently broad compared to the range of product qualities, and just one otherwise. In contrast, our model assumes that consumers are distributed over an interval starting from zero, and we do not assume that the market is completely covered.[5] Deneckere and McAfee (1996) and McAfee

[2] The assumption $\alpha > 1$ means that the development cost function is convex. Assuming that $u > 1$ ensures that the development cost increases as α increases and is made without loss of generality to facilitate the exposition.

[3] Boehm (1981) found that α is 1.05, 1.12, or 1.20, depending on the nature of the project. Banker and Kemerer (1989) found, in a different setting, that $\alpha = 1.49$. Banker and Kemerer's (1989) analysis of scale economies in software development concludes that although increasing returns ($\alpha < 1$) may exist for small projects, decreasing returns ($\alpha > 1$) set in for larger projects.

[4] All proofs are in the appendix.

[5] Both assumptions are important for the results in the respective models.

(2007) show that a monopoly will offer a second "damaged good"—one with the same unit cost but lower quality—if high-value customers have a relatively low value for the damaged good. However, when the high-value customers have a relatively high value of the damaged goods (e.g., when consumers' utility function is linear or convex), the monopoly will not offer the damaged good, because its losses on high-value customers exceed the gains from selling to low-value customers. Wei and Nault (2008) show that in the case of sequential product choice, a monopoly may offer more than one product as a form of entry deterrence. Bhargava and Choudhary (2001, 2008) derive more general conditions under which a multiproduct monopoly will offer a single product or multiple products.

Similar to the case of welfare maximization, monopoly profits are proportional to $N^{[\alpha/(\alpha-1)]}$; i.e., markets for information goods inherently offer returns that are a convex increasing function of the market size *even absent any network effects*. In a larger market, the development cost is amortized over more units, so the firm develops a higher-quality product. Thus, the monopoly not only sells more units, but it does so at a higher price. The rate at which returns increase is determined by the development complexity: as α increases, the cost of improving product quality increases, and the rate at which returns increase decreases. These results depend on the convexity of the development cost function: if the function was concave, a finite solution would not exist because the benefits of increasing quality would always outweigh the cost.[6]

The monopoly serves half of the efficient market size. This "quantity distortion" results from pricing above the efficient price. It is well known (see Spence 1975) that a monopoly may offer a quality that is either higher or lower than the efficient quality. For information goods, we find that there is always a downward quality distortion: the monopoly develops a product that is $(1/2)^{[1/(\alpha-1)]}$ of the efficient quality. Thus, not only are fewer customers being served by a monopoly, they are also being offered a lower-quality product. This quality distortion is a decreasing function of the development complexity α.

3. Duopoly

We next analyze the product choices made by two competing firms in a two-stage game: First, the firms simultaneously choose their product qualities. Then, each firm, having observed the other firm's product choice, simultaneously chooses a price for its product. Our results depend on the assumption of simultaneous product choice; at the end of this section, we also examine what happens when product choice is sequential (see also Wei and Nault 2008 for alternative assumptions).

If the firms choose the same quality, the only equilibrium is to price at unit cost. This results in zero revenue and negative profits for both firms, who would then prefer not to enter the market. We thus look for a product equilibrium in which the firms offer different qualities. By Proposition 2 of Wei and Nault (2008), each firm will offer a single product.[7] Without loss of generality, we assume that Firm 1 offers the higher-quality product, i.e., $u_1 > u_2$. It is straightforward to show that the equilibrium prices are $p_1 = 2u_1(u_1 - u_2)/(4u_1 - u_2)$ and $p_2 = u_2(u_1 - u_2)/(4u_1 - u_2)$. The resulting quantities are $m_1 = 2Nu_1/(4u_1 - u_2)$ and $m_2 = Nu_1/(4u_1 - u_2)$.

Note that $p_1/p_2 = 2u_1/u_2$, so Firm 1 is able to charge twice as much per unit of quality as Firm 2, even though consumer utilities are linear in quality. This reflects the market power of Firm 1, whose product is preferred by all consumers under unit cost pricing. Similarly, Firm 1 serves twice as many consumers as Firm 2, resulting in higher revenue. Firms maximize their profits, given by

$$\Pi_1 = 4Nu_1^2(u_1 - u_2)/(4u_1 - u_2)^2 - ku_1^\alpha,$$
$$\Pi_2 = Nu_1u_2(u_1 - u_2)/(4u_1 - u_2)^2 - ku_2^\alpha.$$

The optimal product qualities solve the following first-order conditions:

$$4u_1(4u_1^2 - 3u_1u_2 + 2u_2^2)/(4u_1 - u_2)^3 = (k/N)\alpha u_1^{\alpha-1}, \quad (1)$$
$$u_1^2(4u_1 - 7u_2)/(4u_1 - u_2)^3 = (k/N)\alpha u_2^{\alpha-1}. \quad (2)$$

Multiplying u_1 and u_2 by a scale factor multiplies the left-hand sides of Equations (1) and (2) by a power of that factor, so for any given α, the solution to Equations (1) and (2) with $N = k = 1$ provides the solution for all possible values of N and k, where we measure product quality in units of $(N/k)^{[1/(\alpha-1)]}$. We have the following proposition:

Proposition 2. *Consider an information-good duopoly with two firms, A and B. There are two simultaneous*

[6] In the case of linear development costs, a monopoly will offer a product of zero quality (not enter the market) or infinite quality, depending on the relative values of the market size N and the development cost coefficient k. In addition, the results of Proposition 1 do not hold when there are network effects (Jing 2003).

[7] In essence, if the two lowest-quality products were offered by the same firm, they would be sold to consumers within an interval $[0, b]$ $(b \le 1)$, and the proof of Lemma 1 shows that within that interval, that firm will be better off eliminating its lowest-quality product without changing what happens in $(b, 1]$. If the two lowest-quality products are offered by different firms, Wei and Nault (2008) show that if the firms alternate, the firm offering the lowest-quality product prefers to drive the quality of that product to zero, which is equivalent to not offering it. If one firm offers the lowest-quality product and the other firm offers the next two higher-quality products, then the latter firm will be better off consolidating the two products.

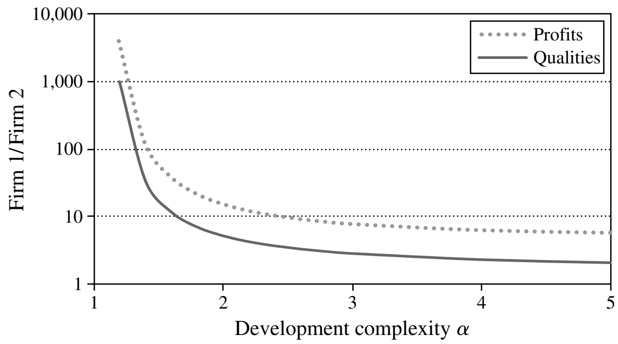
product choice equilibria: *one with Firm A as the higher-quality firm and the other with Firm B as the higher-quality firm. Denoting the higher- and lower-quality firms as Firm* 1 *and Firm* 2, *respectively, the equilibria are given by the unique solution to Equations* (1) *and* (2).

A comprehensive numerical analysis of the results is in Online Supplement A (provided in the e-companion).[8] What is striking about the equilibria is the difference between the two firms. Firm 1's quality is anywhere from more than twice to more than 1,000 times that of Firm 2. Its profits are at least six times greater than those of the lower-quality firm. In each case, Firm 1 uses its market power to choose a quality that is only slightly greater than that of a monopoly. Thus, although both firms differentiate their product qualities to alleviate price competition, most of the burden of differentiation falls on the lower-quality firm.

The ratio of the equilibrium product qualities, u_1^*/u_2^*, is a proxy for the degree of product differentiation. As u_1^*/u_2^* increases, both the ratio of the profits of Firm 1 to those of Firm 2 and the ratio of the profits of Firm 1 to those of a monopoly increase. This quality ratio thus captures the degree to which the higher-quality firm dominates the market and resembles a monopoly. The ratios of product qualities and profits of the two firms are plotted as functions of the development complexity α in Figure 1. Both ratios are decreasing functions of α, and the profit ratio is always greater than the quality ratio. If we fix u_1/u_2, then the ratio of development costs, $(u_1/u_2)^\alpha$, is an increasing function of α—i.e., as α increases the lower-quality firm increasingly enjoys a relative cost advantage over the higher-quality firm. This relative cost advantage is what drives the decrease in the quality ratio as α increases.

Proposition 2 shows that in our model, information-good markets tend to be dominated by a single firm even when a second firm can freely enter the market. Unlike industrial-good markets, where different firms can dominate different market segments (see further discussion in §4), the higher-quality firm in vertically differentiated information-good markets behaves almost like a monopoly. With industrial goods, each consumer type chooses a different product quality under unit cost pricing. As a result, even with vertical product differentiation, markets for industrial goods have an inherent segmentation that lessens price competition. This is not the case for information-good markets, where all consumers prefer the higher-quality product not just in absolute terms but also under unit cost pricing. This gives

Figure 1 **Ratios of Product Qualities and Profits for an Information-Good Duopoly as Functions of the Development Complexity α (Logarithmic Scale)**



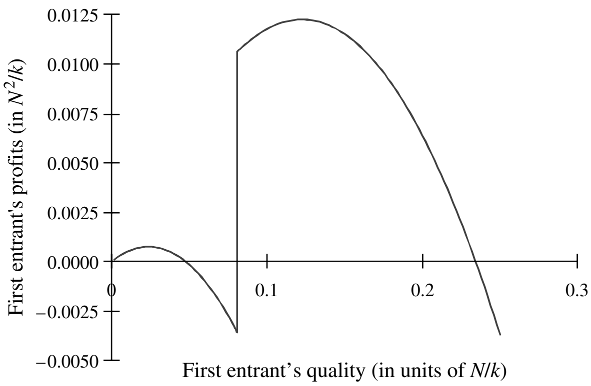
the higher-quality firm significant market power. Moreover, to lessen price competition, firms have to differentiate their products to a greater extent in markets for information goods, which creates a greater distance between the quality levels of the high- and low-quality firms. As a result of these two factors, the higher-quality information-good firm chooses almost the same product quality as a monopoly, serves twice as much of the market as the lower-quality firm, and generates profits that are at least six times greater than those of the lower-quality firm.

Our results show that the dominance of the leading firm decreases with the complexity of product development. As the complexity increases, u_1^*/u_2^* decreases, and the higher-quality firm faces more competitive pressure from the lower-quality firm. As a result, the profits of the higher-quality firm as a percentage of those of a monopoly decrease from more than 99% to 58% as α increases from 1.2 to 5. Thus, fundamental advances in development processes that change the shape of their cost function, i.e., changes that decrease the exponent α, cause markets for information goods to be dominated by a single firm to an even greater extent. In contrast, changes to the scale parameter k do not impact the market outcome in terms of the ratio of the equilibrium product qualities or the profits of the higher-quality firm as a percentage of those of a monopoly.

Similar to the monopoly case (see discussion following Proposition 1), our results depend on the specific assumptions of our model, including linear utility function, consumers uniformly distributed over $[0, 1]$, the shape of the development cost function, and simultaneous product choice. Wei and Nault (2008) consider the case of sequential product choice, allowing for versioning and entry deterrence. We can examine the sensitivity of our results to the assumption of simultaneous product choice by considering numerically what happens under sequential product choice when $\alpha = 2$. Figure 2 shows the first entrant's

[8] An electronic companion to this paper is available as part of the online version that can be found at http://mansci.journal.informs.org/.

Figure 2 **Information-Good First Entrant's Profits as a Function of Its Product Choice for $\alpha = 2$**



profit function in an information-good duopoly with sequential product choice followed by simultaneous pricing decisions by the two firms. The profit-maximizing product choice for the first entrant is such that the second entrant chooses to be the lower-quality firm. Compared to the simultaneous product choice case, we find that both firms choose slightly lower product qualities, offer slightly lower prices, and serve slightly more of the market. Clearly, the first entrant has more market power in the sequential case than in the simultaneous case. Thus, as expected, Firm 1's profits are higher, Firm 2's profits are lower, and both consumer surplus and social welfare are lower. These differences, however, are small: Firm 1's profits are less than 1% higher and Firm 2's profits are less than 1% lower, and both consumer surplus and social welfare are less than 3% lower. The key advantage of being the first entrant is in securing the higher-quality product position. Thus, our key insights stay intact.

4. Information Goods vs. Industrial Goods Comparison

For *information goods*, the unit production and distribution cost is negligible compared to the amortized development cost. In contrast, with *industrial goods*, the key cost factor is the (quality-dependent) unit production cost. In this section, we show that our results for information goods are sharply different from those for industrial goods. Our industrial-good benchmark is Moorthy (1988), which studies single- and two-product market outcomes for goods that have unit costs of $c \cdot u^2$ ($c > 0$) and zero development costs. Moorthy's results for industrial goods depend on the convexity of the unit cost function, just as our results for information goods depend on the convexity of the development cost function.

4.1. Welfare Maximization and Monopoly

In contrast to information goods, under unit cost pricing each consumer type has its own efficient product, i.e., consumers have heterogeneous ideal points. Thus, the multiproduct welfare-efficient solution offers all products in the interval of efficient products and prices, each at its unit cost. Thus, with industrial goods, offering more products increases overall welfare. Because consumers have heterogeneous ideal points for industrial goods, it is easier for a monopoly to segment the different consumer types. Furthermore, and again in contrast to the case of information goods, an industrial-good monopoly offers the efficient product quality; i.e., there is no "quality distortion" in markets for industrial goods.

4.2. Duopoly

The segmentation inherent in industrial-good markets helps insulate firms from price competition, so firms do not differentiate their products to the same degree as in information-good markets. Comparing our model of information goods with quadratic development costs to Moorthy's (1988) benchmark of industrial goods with quadratic unit costs, the higher-quality firm's product quality is 2.1 times larger than the lower-quality firm's for an industrial-good duopoly and 5.3 times larger for an information-good duopoly. Because all consumers prefer the higher-quality information good under marginal cost pricing, the higher-quality duopolist has considerable market power, which it uses to choose a product quality within 3% of a monopoly's. The quality offered by the monopoly is the most desirable product quality in that it best trades off the cost of providing the product against consumers' willingness to pay for it. In an industrial-good duopoly, neither firm has the market power to get close to the quality offered by a monopoly. This relative lack of market power is also reflected in the demands: Whereas the higher-quality firm serves the more profitable consumer types, the lower-quality firm serves more of the market. With information goods, the higher-quality firm serves twice as many consumers as the lower-quality firm.

With information goods, the profits of the higher-quality duopolist are at least six times greater than those of the lower-quality duopolist. In contrast, with industrial goods, the higher-quality firm's profits are only 1.4 times greater than those of the lower-quality firm. In markets for information goods, the higher-quality firm uses its market power to both choose a product quality very similar to that of a monopoly and to serve more of the market. In addition, the burden of greater differentiation falls on the lower-quality firm, which offers a much lower product quality and is left with a much smaller percentage of sales and total profits. In contrast, with industrial goods, the firms' product qualities are not as differentiated and are much more symmetrically distributed around

Figure 3 Ratios of Product Qualities and Profits for a Good with Quadratic Development and Unit Costs with $k = N = 1$ as Functions of the Unit Cost Coefficient c

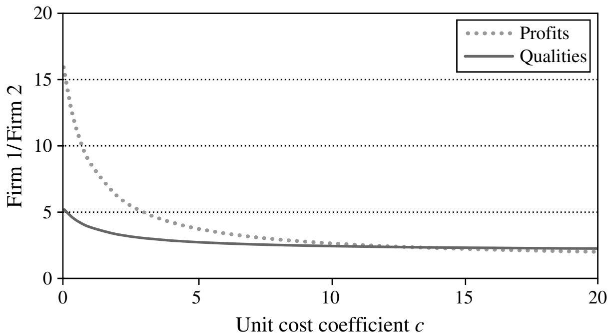
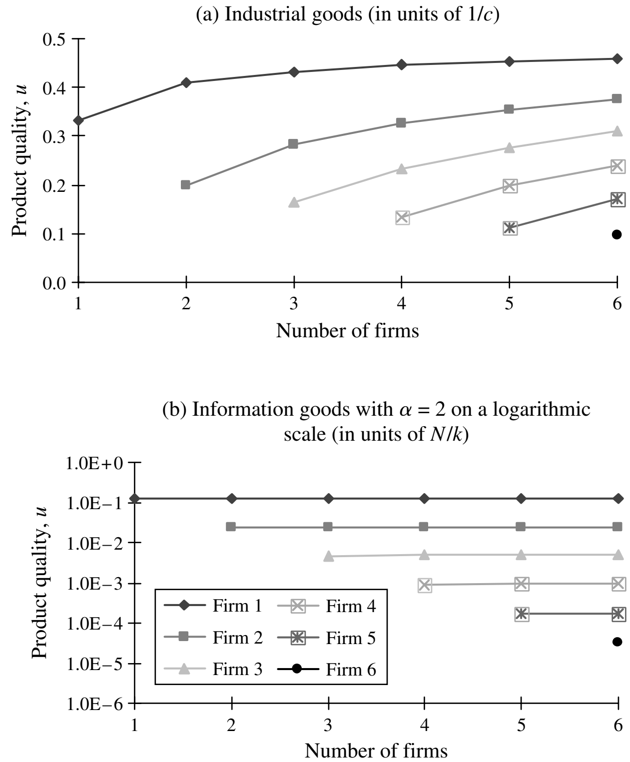


Figure 4 Oligopoly Product Choices u_i as a Function of the Number of Firms



that of a monopoly, with the lower-quality firm actually serving more of the market. As a result, the allocation of profits is more balanced.

Naturally, our results depend on the cost forms employed. First, if the unit cost is positive, but independent of quality, then our information-good results continue to hold after a transformation that takes into account the constant unit cost (e.g., the welfare-efficient price will be the constant unit cost rather than zero). Further, our results extend to the more general case of goods that have both positive development costs and unit costs. We have solved for the duopoly outcomes for products with both quadratic development and unit costs with $k = N = 1$. The ratios of the product qualities and profits are plotted as functions of the unit cost coefficient c in Figure 3. For $c = 0$, the good is a pure information good and the results coincide with those of §3. As the unit cost coefficient c increases, the importance of unit costs increases and the good becomes more of an industrial good. As c increases, the ratio of product qualities decreases from 5.25 (for information goods) toward 2.1 (for industrial goods), and the ratio of profits decreases from 16 toward 1.4. Thus, "pure" information goods with no unit costs and "pure" industrial goods with no development costs are extreme points of the spectrum of all products, and the market outcomes are determined by the relative significance of the unit and development costs. We have also examined the case of industrial goods with unit costs of $c \cdot u^\alpha$. The ratio of equilibrium product qualities is a decreasing function of the unit cost function exponent, paralleling the impact of the development cost function exponent with information goods.

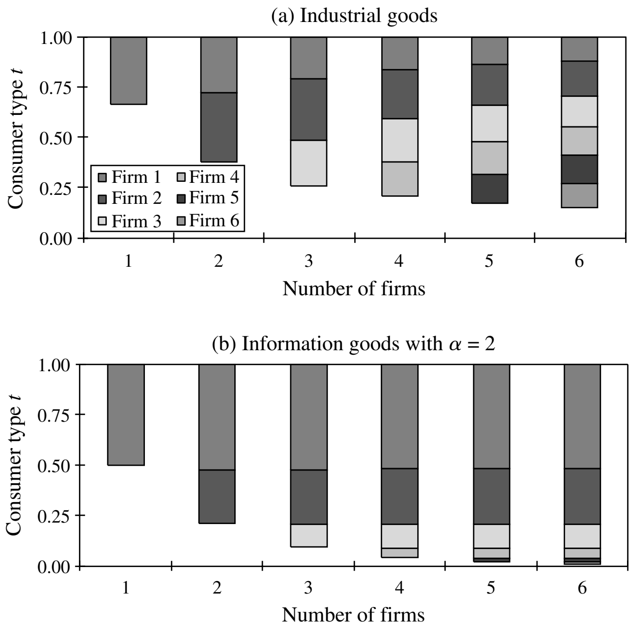
4.3. Oligopoly

The comparison between industrial and information goods is even more striking for an oligopoly. As usual, it is difficult to derive closed-form results for $n > 2$ firms. Thus, we numerically solve for the n-firm, single-product, simultaneous product equilibrium ($n = 1, 2, \ldots, 6$) for both industrial goods with quadratic unit costs and information goods with quadratic development costs ($\alpha = 2$). Just as in the duopoly case, firms first choose product qualities and then prices. Figures 4–8 show the resulting product qualities (u_i), quantities (m_i), profits (Π_i), and allocation of social welfare for these parameter values.

Figures 4(a) and 4(b) show the product choices as functions of the number of firms. For industrial goods, as the number of firms increases, their product choices tend to span the efficient product space, $[0, 1/(2c)]$, leading to a roughly arithmetic distribution of product qualities that is highly dependent on the number of firms. In contrast, the qualities offered in an information-good market are not sensitive to the number of firms, and the highest quality in each case is about 51% of the efficient product quality for our parameter values. Moreover, the relation between adjacent product qualities is approximately geometric, with u_i/u_{i+1} $(i = 1, \ldots, N-1)$ within 5% of u_1/u_2 of the duopoly case.

Figures 5(a) and 5(b) show how the sources of demand change with the number of firms for our numerical example. Consistent with classical results, competition in the industrial-good market intensifies as the number of firms increases: an increase in the number of firms increases market coverage, while decreasing each firm's market share. In information-good markets, adding a firm does not significantly

Figure 5 **Oligopoly Sources of Demand m_i as a Function of the Number of Firms**

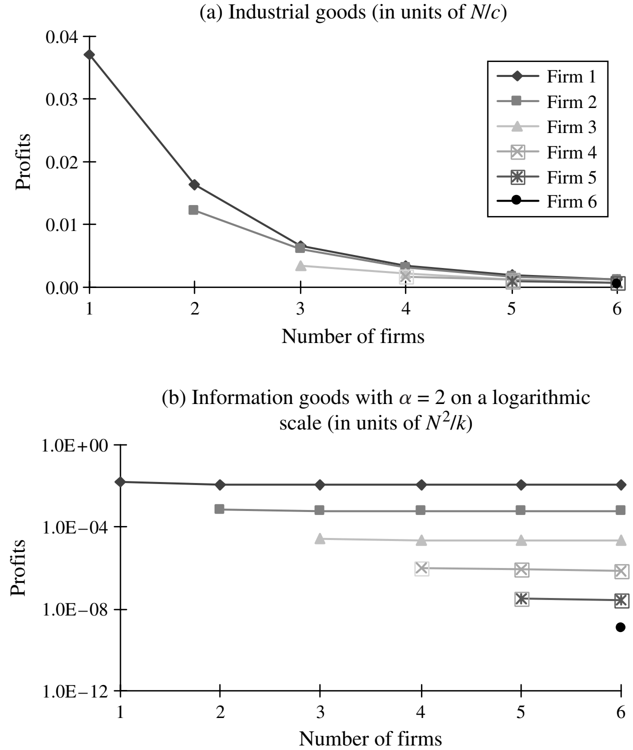


impact the sources of demand of existing firms. If there is only one firm, it serves the top half of the market. In an oligopoly, the highest-quality firm serves slightly more than the top half the market. The second-highest-quality firm serves approximately the top half of the market left unserved by the highest-quality firm—as if that firm acts like a monopoly in the residual market, and the quantity ratio of adjacent firms, m_i/m_{i+1}, is approximately two. Thus, adding a firm to an information-good oligopoly does not significantly impact the sources of demand of existing firms, while adding a firm to an industrial-good oligopoly does change the sources of demand.

Figures 6(a) and 6(b) show the corresponding profits. The profits of each industrial-good firm rapidly decrease toward zero as the number of firms increases, whereas in the information-good case the individual firms' profits are not nearly as sensitive to the number of firms: the profit of the marginal firm decreases some as another firm enters the market and it faces competition from below for the first time. However, the profits of the firms above it do not change significantly. Thus, the highest-quality firm dominates the market, earning at least 94% of total industry profits, with the second-highest-quality firm earning at least 4.9%, the third less than 0.25%, and the remaining firms less than 0.01%.

Figure 7 shows the profits of the highest-quality firm as a percentage of those of a monopoly. The profits of the highest-quality industrial-good firm decrease to 18% of those of a monopoly as the number of firms increases from one to three, and further decrease to just 3% of those of a monopoly as the number of firms increase from three to six. The profits of the highest-quality information-good firm only decrease to 47% of those of a monopoly as the number of firms increases from one to three, and remain above 45% of those of a monopoly even with six firms.

Figure 6 **Oligopoly Firm Profits Π_i as a Function of the Number of Firms**



Figures 8(a) and 8(b) compare social welfare and its components. As the number of industrial-good firms increases, total industry profits and the welfare loss decrease to zero and consumer surplus approaches the welfare-efficient outcome of $N/(12c)$. For information goods, both consumer surplus and total industry profits rapidly level off as the number of firms increases. Moreover, the maximum social welfare is less than 56% of the welfare-efficient outcome, i.e.,

Figure 7 **Profits of the Highest-Quality Firm in an Oligopoly as a Percentage of Those of a Monopoly as a Function of the Number of Firms**

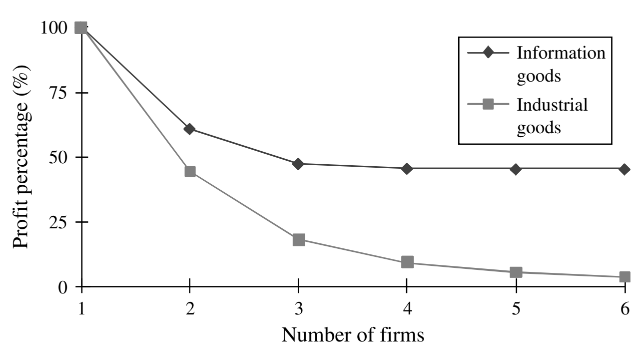
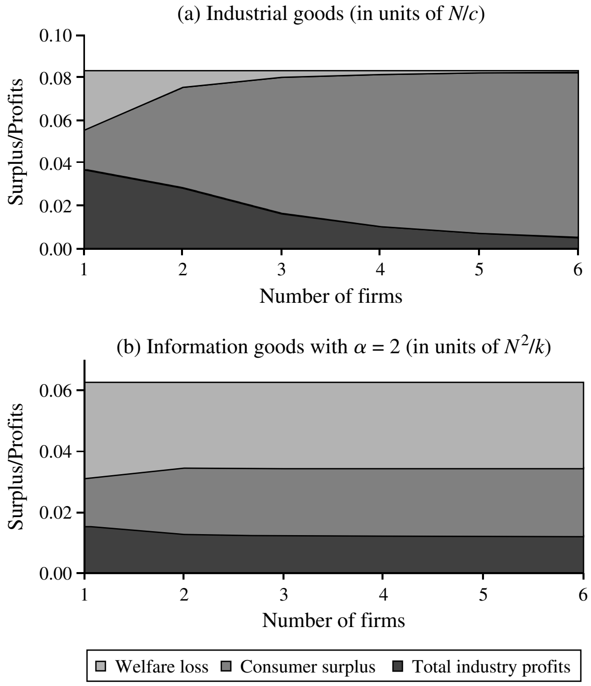


Figure 8 Social Welfare and Its Components (Consumer Surplus and Total Industry Profits) in an Oligopoly as a Function of the Number of Firms



a significant welfare loss persists. The sum of all of the development costs for all firms except Firm 1 is less than 2.1% of the welfare loss, so the duplicate development costs are not the primary source of the welfare loss. Thus, although entry reduces profits and increases both consumer surplus and social welfare in markets for industrial goods, it only has a small effect in markets for information goods. In fact, increasing the number of firms beyond two actually has a negative impact on welfare, although the effect is small.

The relationship between profits and market size is similar to the case of monopoly: the profits of information-good firms are convex and increasing in market size. We find that information goods are characterized by increasing returns even without network effects.

Needless to say, these results depend on the parameter values. The impact of development complexity on oligopoly markets for information goods is consistent with our findings in the duopoly case.[9] As α increases, the ratio of product qualities decreases. Thus, at the margin, price competition increases with α, and firms compensate in part by serving slightly more of the market, but the ratio of the demands of adjacent firms, m_i/m_{i+1}, remains approximately two. The increasing price competition also causes the profit ratios Π_i/Π_{i+1} to decrease as α increases.

[9] The oligopoly results for information goods for $\alpha = 1.5$ and $\alpha = 4$ are in Online Supplement B (provided in the e-companion).

In summary, markets for industrial and information goods are vastly different. The market power of the leading firm we found in an information-good duopoly persists when there are more firms in the market. In our oligopoly model, firms simultaneously choose product qualities and then simultaneously choose prices. We find that for this model, the product choices in an information-good oligopoly are approximately geometrically distributed, and the highest-quality firm continues to operate near the monopoly outcome, both in terms of product quality and profits, as the number of firms increases. In contrast, the product choices in the corresponding industrial-good market are approximately arithmetically distributed, and total profits are roughly evenly split and decrease toward zero as the number of firms increases. Whereas free entry brings about the welfare-efficient outcome in markets for industrial goods, it does not in markets for information goods, where the market continues to be dominated by the highest-quality firm.[10]

5. Discussion

Markets for information goods differ significantly from markets for industrial goods. We find that these differences are fundamental, encompassing everything from the impact of entry to the effect of an increase in market size. Information-good markets are dominated by a single firm because they lack the segmentation inherent in industrial-good markets, which mitigates the effects of price competition. Instead, information-good firms have to differentiate their products to a greater degree to alleviate price competition. The combination of the higher-quality firm choosing a product similar to that of a monopoly and the greater product differentiation leads to an equilibrium in which the higher-quality firm enjoys profits that are much greater than those of the lower-quality firm in a duopoly and a significant percentage of those of a single-product monopoly. Our results also suggest that markets for information goods are characterized by quality distortion that decreases in development complexity.[11] Information-good markets

[10] This holds under our assumption of simultaneous entry with a sequential choice of quality and then price. Recall that in the case studied at the end of §3, the dominance of the higher-quality firm was even greater in a duopoly with *sequential* entry.

[11] We suspect some readers may have been the victims of this quality distortion, which can result in a substantial social loss. By analysts' estimates, approximately one billion PCs run Windows. If a better operating system saved the average user just one minute per workday, the benefit, at \$10 per hour, would be approximately \$40 billion a year. Given that Microsoft's total R&D expense for all products in 2009 was less than one-quarter this amount, the social benefit of improved quality would likely have far exceeded the cost. Of course, Microsoft is trying to maximize profits, not social welfare.

are further characterized by increasing returns: as the market size increases, firms not only sell more units, but they also improve the quality of their product, and they sell it at a higher price.

Similar to other research in this area (e.g., most of Table 1), our results are based on a stylized model of vertical product differentiation. In reality, not only are there more general customer preferences, but there is also a mix of vertical and horizontal differentiation, where the latter allows firms to soften the competition through specialization. Then, similar to the industrial-goods case, different consumers have different ideal points, and different firms will target their products to different customer segments. In contrast, our results correspond to the case where all consumers prefer higher quality when products are priced at unit cost, so the leading firm captures a very large high-quality segment and its competitors serve very small, residual segments. The key driver of our results is the universal preference for the highest-quality product; as long as this is the dominant market factor, we expect our substantive results to follow. As shown in §4, our results extend beyond pure information goods, that is, zero unit cost is not a singular point where our results apply: the patterns we identify apply to markets with positive unit costs (both quadratic in quality and independent of quality) as long as the development costs are dominant.

5.1. Examples

The high concentration in markets for information goods, or for industrial goods with a high information content, is consistent with the predictions of our model. In the microprocessor market, the leading players are Intel and AMD (Advanced Micro Devices). In 2008, Intel's revenue share was in excess of 80%, AMD's share was 12%, and all others accounted for less than 8% (CIOL 2009). It is well known that Intel's microprocessors have better performance and a higher price (in 2007, Intel's average unit price was almost twice that of AMD). This behavior is consistent with that predicted by our model, although microprocessors are of course not pure information goods. However, even with a positive unit cost, our predictions continue to hold as long as the unit cost is relatively low. Intel's gross margin excluding depreciation is approximately 65%, much higher than for most manufacturers. Hence, the high concentration and quality–price relationship predicted by our model are also observed in the microprocessor market.

Another case in point is the authoring and publishing software market. According to IDC (International Data Corporation), between 2004 and 2007, Microsoft's share of this market was approximately 80%, Adobe was second with about 12%–13% of the market, and Corel was third with a 1% share. Although in this market both horizontal and vertical differentiation are significant, its structure is consistent with the predictions of our model.[12] Indeed, Liebowitz and Margolis (1999) find that product quality is a key determinant of market shares in software markets. Microsoft also dominates the market for spreadsheets and is a strong player in a number of other products. This phenomenon is not limited to Microsoft (for example, Intuit dominates the tax preparation market and Oracle dominates the database market), but it is certainly well understood by the company: Bill Gates believes that Microsoft will "only make money ... where we're No. 1 or No. 2" (Wasserman 1997, p. E1).

Software markets and other information-good markets are characterized not only by quality differentiation but also by network effects, which are known to result in high market concentration (see Katz and Shapiro 1994, Shapiro and Varian 1999, Economides and Flyer 1997, Eisenmann et al. 2006). In these cases, our model provides an alternative explanation that can be evaluated vis-à-vis the network effects. In the search market, for example, we expect consumers' switching costs to be low because a competing site is only a click away. Thus, our model provides an explanation for the high concentration in this market (in November 2009, Google's U.S. search query share was 65.6% compared to 17.5% for Yahoo! and 10.3% for Microsoft).[13]

5.2. Implications

As discussed above, a number of information-good markets are characterized by network effects, which lead to concentrated markets. From the users' perspective, problems associated with network effects can be addressed through compatible standards that are promulgated and enforced by industry bodies or regulators to eliminate or weaken their root cause. It is commonly believed that with new compatibility standards, Web services that break the network-effect lock of entrenched platforms, and service-oriented architectures that reduce switching costs, free entry will lead to highly competitive technology markets.

Our results suggest that this is less likely to happen in markets where vertical quality differentiation is important. The increasing returns in our model are endogenously derived rather than being assumed. Absent any demand-side externalities, switching costs, or incompatibilities, information-good markets

[12] The three major players have Windows-based products, which neutralizes the usual network effects between operating systems and applications.

[13] Based on comScore qSearch. comScore considers the number of searches per searcher, which is about twice as high for Google as it is for Microsoft and Yahoo!, as a measure of the quality of the search experience.

are still highly concentrated and exhibit increasing returns even with free entry and fair competition. In our model, entry has only a minuscule effect on the leading firm: even with free, costless entry, markets for information goods have the "look and feel" of a monopoly, with consumer surplus remaining essentially unchanged as the number of firms increases. Our results show that there is no guarantee that weakening or eliminating network effects would eliminate market concentration. Commentators and chief information officers have argued for increasing compatibility in various technology markets ranging from electronic medical records to storage, Web services, and telecommunications. However, these developments, which reduce horizontal differences, tend to increase the relative importance of vertical quality differentiation. Our findings suggest that this may result in more concentrated markets.

The implications for technology vendors are profound as well. As shown by Shapiro and Varian (1999, Chaps. 6–8), network-effects-based strategies include, among others, building an installed base through penetration pricing and first-move, raising customers' switching costs, managing the trade-off between openness and control, and controlling standards. Lee and Mendelson (2007) show how under network effects, vendors also compete through elaborate market segmentation, product tweaking, timing, and pricing strategies. Our analysis shifts the focus from such tactics to investments in product development. In our model, vendors win when their product is of fundamentally higher quality; once they win, they can dominate the market and extract much of the surplus. Within this context, it is the investment in engineering effort and product quality that really matters.

5.3. Future Research

Our model is a single-attribute model of vertical product differentiation. With multiattribute models, it may be possible to study the trade-offs between different quality-like characteristics such as ease of use and functionality. Our examples suggest that it will be interesting to consider the effects of adding horizontal product differentiation to our model (see Wei and Nault 2009). As discussed above, we have not considered what will happen in a market that combines vertical product differentiation with network effects, and it will be interesting to consider the interaction between these factors in an oligopoly. Further, our analysis uses a particular utility function that makes the model more tractable. However, Proposition 1, for example, will not hold for some other utility functions (Deneckere and McAfee 1996),[14] suggesting that extending the analysis to other functional forms will be valuable. On the cost side, our results are limited to the case of convex development cost functions, and it will be interesting to consider extensions that allow more general functional forms.

[14] See, however, Bhargava and Choudhary (2001, 2008).

6. Electronic Companion

An electronic companion to this paper is available as part of the online version that can be found at http://mansci.journal.informs.org/.

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Appendix. Proofs

Proof of Proposition 1. Lemma 1 shows that a multiproduct monopoly will only offer a single product. Given that, the monopoly profits are given by the difference between its revenue ($p \cdot m$) and its development cost ($k \cdot u^\alpha$). For a given product quality u, the profit-maximizing price is $u/2$. Plugging this price into the profit equation and maximizing with respect to u gives the profit-maximizing quality $(N/4\alpha k)^{[1/(\alpha-1)]}$, and the other results directly follow. □

Lemma 1. *A multiproduct information-good monopoly will only offer a single product.*

The proof is by induction. The base case is trivially true. The inductive step is proved by contradiction. Assume that a monopoly with the ability to offer $M+1$ products maximizes its profits by offering more than one product, so the demand for each product is positive. By the inductive hypothesis, if the monopoly were not to offer all $M+1$ products, it must offer a single product. Hence, we assume that the monopoly offers all $M+1$ products. Label the products such that $u_1 > u_2 > \cdots > u_M > u_{M+1}$. Further, let $p_1, p_2, \ldots, p_M, p_{M+1}$ be the prices that maximize the monopoly's profits for those $M+1$ products. Now consider removing the lowest-quality product u_{M+1} from the market (or, equivalently, pricing it so no consumer chooses to buy it) and leaving the prices of the other M products unchanged. The profits generated by the $M-1$ highest-quality products will remain the same, whereas the profits generated by u_M will increase (because more consumers will choose it), and the profits generated by u_{M+1} will drop to zero. We now show that this will increase the firm's profits.

Let t_M be the consumer that is just indifferent between u_{M-1} and u_M, and let t_{M+1} be the consumer who is just indifferent between u_M and u_{M+1}. Then, $t_M = (p_{M-1} - p_M)/(u_{M-1} - u_M)$ and $t_{M+1} = (p_M - p_{M+1})/(u_M - u_{M+1})$. With both u_M and u_{M+1} in the market, $m_M = N(t_M - t_{M+1})$ and $m_{M+1} = N(t_{M+1} - p_{M+1}/u_{M+1})$. Thus, the profits generated from these two products are $p_M m_M + p_{M+1} m_{M+1} = p_M N(t_M - t_{M+1}) + p_{M+1} N(t_{M+1} - p_{M+1}/u_{M+1})$.

With only u_M in the market, $m_M = N(t_M - p_M/u_M)$, and the profits generated by u_M are $p_M m_M = p_M N(t_M - p_M/u_M)$. The net change in profits from removing u_{M+1} from the market and keeping all other prices the same is then

$$\begin{aligned} &p_M N(t_M - p_M/u_M) \\ &\quad -[p_M N(t_M - t_{M+1}) + p_{M+1} N(t_{M+1} - p_{M+1}/u_{M+1})] \\ &\quad = N(p_M u_{M+1} - p_{M+1} u_M)^2 / [u_M u_{M+1}(u_M - u_{M+1})] > 0, \end{aligned}$$

where the last inequality follows from the fact that $u_M > u_{M+1} > 0$. Thus, removing u_{M+1} from the market results in a net increase in profits, a contradiction to the optimality of offering $M+1$ products. □

Proof of Proposition 2. Dividing Equation (1) by Equation (2) gives $4(4u_1^2 - 3u_1u_2 + 2u_2^2)/u_1(4u_1 - 7u_2) = (u_1/u_2)^{\alpha-1}$. Letting $u_2 = zu_1$ and simplifying, we have

$$z^{\alpha-1} = (4-7z)/[4(4-3z+2z^2)]. \tag{3}$$

The left-hand side of (3) is zero for $z=0$ and is an increasing function of z, and the right-hand side is $1/4$ for $z=0$, zero for $z=4/7$, negative for $z>4/7$, and a decreasing function of z over $[0, 4/7]$. Hence, for any $\alpha > 1$, Equation (3) has a unique solution $z(\alpha)$ satisfying $0 < z(\alpha) < 4/7$. Substituting into Equation (2), we obtain

$$(u_2^*)^{\alpha-1} = (N/k)(4-7z)/[\alpha(4-z)^3] \tag{4}$$

and

$$u_1^* = u_2^*/z. \tag{5}$$

It is straightforward to show that both objective functions are concave. Hence, given that $u_1 > u_2$, the product qualities u_1^* and u_2^* uniquely maximize the respective profits.

To complete the proof, we need to consider the possibility of switching. Fix $u_1 = u_1^*$ and consider the case where Firm 2 decides to switch to become the higher-quality firm. The first-order condition for maximizing $u_2 = u$ over (u_1, ∞) is $4u(4u^2 - 3uu_1 + 2u_1^2)/(4u - u_1)^3 = ((k\alpha)/N) \cdot u^{\alpha-1}$. Letting $u_1 = ru$ and simplifying, we have

$$r^{\alpha-1} 4(4-3r+2r^2)/(4-r)^3 = ((k\alpha)/N)u_1^{\alpha-1}. \tag{6}$$

Letting $u_2 = zu_1$, Equation (1) becomes $4(4-3z+2z^2)/(4-z)^3 = ((k\alpha)/N)u_1^{\alpha-1}$.

Combining this equation with Equation (6) gives

$$r^{\alpha-1}(4-3r+2r^2)/(4-r)^3 = (4-3z+2z^2)/(4-z)^3. \tag{7}$$

The first-order condition is sufficient because the objective function is concave. Further, Equation (7) has a unique solution r in $(0, 1)$. A direct comparison of Firm 2's profits under the nonswitched solution (when it chooses u_2^*) and the switched solution (when it chooses u_1^*/r, where r is specified by Equation (7)) shows that for all α, Firm 2's profits are higher if it does not switch.

Similarly, considering the case where Firm 2 chooses u_2^* and Firm 1 decides to switch to being the lower-quality firm, the first-order condition for Firm 1 with $u_1 = u$ over $(0, u_2^*)$ is $u_2^2(4u_2 - 7u)/(4u_2 - u)^3 = ((k\alpha)/N)u^{\alpha-1}$.

Letting $u = qu_2$ and simplifying, we have

$$(1/q)^{\alpha-1}(4-7q)/(4-q)^3 = ((k\alpha)/N)u_2^{\alpha-1}. \tag{8}$$

Letting $u_2 = zu_1$, Equation (2) becomes $(4-7z)/(4-z)^3 = ((k\alpha)/N)u_2^{\alpha-1}$.

Combining this equation with Equation (8) gives

$$(1/q)^{\alpha-1}(4-7q)/(4-q)^3 = (4-7z)/(4-z)^3, \tag{9}$$

which has a unique solution q in $(0, 1)$. Concavity of the objective function shows that the first-order condition is sufficient, and a direct comparison shows that Firm 1's profits are lower under the switched regime for all α. □

References

Bakos, Y., E. Brynjolfsson. 1999. Bundling information goods: Pricing, profits, and efficiency. *Management Sci.* **45**(12) 1613–1630.

Banker, R. D., C. F. Kemerer. 1989. Scale economies in new software development. *IEEE Trans. Software Engrg.* **15**(10) 416–429.

Benediktsson, O., D. Dalcher, K. Reed, M. Woodman. 2003. COCOMO-based effort estimation for iterative and incremental software development. *Software Quality J.* **11**(4) 265–281.

Bhargava, H. K., V. Choudhary. 2001. Information goods and vertical differentiation. *J. Management Inform. Systems* **18**(2) 89–106.

Bhargava, H. K., V. Choudhary. 2008. When is versioning optimal for information goods? *Management Sci.* **54**(5) 1029–1035.

Boehm, B. W. 1981. *Software Engineering Economics*. Prentice Hall, Englewood Cliffs, NJ.

Boehm, B. W., C. Abts, S. Chulani. 2000. Software development cost estimation approaches—A survey. *Ann. Software Engrg.* **10**(1–4) 177–205.

Bonanno, G. 1986. Vertical differentiation with Cournot competition. *Econom. Notes* **15**(2) 68–91.

Brooks, F. P. 1995. *The Mythical Man-Month: Essays on Software Engineering, 20th Anniversary Edition*. Addison-Wesley, Reading, MA.

Choi, C. J., H. S. Shin. 1992. A comment on a model of vertical product differentiation. *J. Indust. Econom.* **40**(2) 229–232.

CIOL. 2009. Intel unleashes Atom bomb on competition in 2008. (April 2), http://www.ciol.com/semicon/biz-watch/news-reports/intel-unleashes-atom-bomb-on-competition-in-2008/2409117926/0/.

Deneckere, R., R. P. McAfee. 1996. Damaged goods. *J. Econom. Management Strategy* **5**(2) 149–174.

Dewan, R., M. Freimer, A. Seidmann. 2000. Organizing distribution channels for information goods on the Internet. *Management Sci.* **46**(4) 483–495.

Economides, N., F. Flyer. 1997. Compatability and market structure for network goods. Working paper, New York University, New York.

Eisenmann, T., G. Parker, M. V. Alstyne. 2006. Strategies for two-sided markets. *Harvard Bus. Rev.* **84**(10) 92–101.

Gabszewicz, J. J., A. Shaked, J. Sutton, J.-F. Thisse. 1986. Segmenting the market: The monopolist's optimal product mix. *J. Econom. Theory* **39**(2) 273–289.

Jing, B. 2003. Market segmentation for information goods with network externalities. Working paper, New York University, New York.

Katz, M., C. Shapiro. 1994. Systems competition and network effects. *J. Econom. Pespect.* **8**(2) 93–115.

Lee, D., H. Mendelson. 2007. Adoption of information technology under network effects. *Inform. Systems Res.* **18**(4) 395–413.

Lehmann-Grube, U. 1997. Strategic choice of quality when quality is costly: The persistence of the high-quality advantage. *RAND J. Econom.* **28**(2) 372–384.

Liebowitz, S. J., S. E. Margolis. 1999. *Winners, Losers and Microsoft*. The Independent Institute, Oakland, CA.

McAfee, R. P. 2007. Pricing damaged goods. *Economics*, no. 2007-1, http://www.economics-ejournal.org/economics/journalarticles/2007-1.

Moorthy, K. S. 1988. Product and price competition in a duopoly. *Marketing Sci.* **7**(2) 141–168.

Motta, M. 1993. Endogenous quality choice: Price vs. quantity competition. *J. Indust. Econom.* **41**(2) 113–131.

Mussa, M., S. Rosen. 1978. Monopoly and product quality. *J. Econom. Theory* **18**(2) 301–317.

Parker, G. G., M. W. Van Alstyne. 2005. Two-sided network effects: A theory of information product design. *Management Sci.* **51**(10) 1494–1504.

Rochet, J.-C., J. Tirole. 2003. Platform competition in two-sided markets. *J. Eur. Econom. Assoc.* **1**(4) 990–1029.

Shaked, A., J. Sutton. 1982. Relaxing price competition through product differentiation. *Rev. Econom. Stud.* **49**(1) 3–13.

Shaked, A., J. Sutton. 1983. Natural oligopolies. *Econometrica* **51**(5) 3–13.

Shapiro, C., H. R. Varian. 1999. *Information Rules*. Harvard Business School Press, Boston.

Spence, A. M. 1975. Monopoly, quality, and regulation. *Bell J. Econom.* **6**(2) 417–429.

Sundararajan, A. 2004. Nonlinear pricing of information goods. *Management Sci.* **50**(12) 1660–1673.

Tirole, J. 1988. *The Theory of Industrial Organization*. MIT Press, Cambridge, MA.

Wasserman, E. 1997. Microsoft's online test. *San Jose Mercury News* (September 15) E1.

Wei, X., B. R. Nault. 2008. Vertically differentiated information goods: Monopoly power through versioning. Working paper, University of Calgary, Alberta, Canada.

Wei, X., B. R. Nault. 2009. Monopoly versioning of information goods when consumers have group tastes. Working paper, University of Calgary, Alberta, Canada.

Wu, S., P. Chen, G. Anandalingam. 2003. Fighting information goods piracy with versioning. *Proc. 24th Annual Internat. Conf. Inform. Systems*, Association for Information Systems, Atlanta.