Market Segmentation for Information Goods with Network Externalities

Bing Jing

Stern School of Business
New York University
Phone: (212) 998-0822
Email: bjing@stern.nyu.edu

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Abstract

Positive externalities characterize the consumption of a majority of information goods such as software, various Internet services, and online communities. In a simple model of vertical differentiation, we show that network externality is a critical factor for the versioning of such information goods. In particular, a multi-product monopolist offers two versions of distinct qualities. The underlying rationale is that offering the low-end version expands the network size and thus enhances the (network) value of the high-end version, allowing the firm to charge a higher price for the high-end version. In addition, we show that the low-quality version may be offered for free under very general conditions. Competition between firms producing compatible products reduces their incentive to version their products due to the spillover effects in a shared product network.

(*Information Goods; Network Externality; Market Segmentation)*

1 Introduction

1.1 Research Motivation

Information goods have undergone phenomenal growth in recent decades, to a large extent due to the widespread adoption of new technologies such as personal computers and the Internet. Information goods are distinguished for their cost structure. A higher quality model of physical goods typically has a higher unit cost, but the unit cost of information goods remains flat as quality improves. For instance, a higher-quality version of software or music costs just as much to reproduce as a lower-quality version. In a vertical setting, recent research by Jones and Mendelson (1998) and Bhargava and Choudhary (2001) has examined the effect of this distinct cost structure on the market segmentation of information goods. Assuming that consumers have constant marginal willingness to pay for quality, they reveal a startling result that, in the absence of externalities, a multi-product monopolist offers only its top-quality version. The rationale underlying their result is that, in markets with such demand and cost features, the benefits of price discrimination do not justify the costs of the resulting cannibalization.

Besides their distinct cost structure, many information goods such as software, online services, and community sites also demonstrate salient network externalities: the larger a product's user base, the greater its value becomes. Such demand-side scale economies mainly arise from users' need to exchange messages and learning tips and transfer data, documents, and program files. How would network externalities affect the firm's versioning strategy? Addressing this question is the central task of the present paper. In the presence of network externalities, we show that the firm has the incentive to expand its product network through second-degree price discrimination. The multi-product monopolist should also offer a lower quality version besides its top quality version. Under very general conditions, the low-end version should be offered at/below marginal cost for the firm to fully exploit the network effects. Our findings appear to be consistent with observed practices in many Internet services, online communities, and certain classes of software. For firms in shared product networks, we show that the optimal structure of their product lines may also depend on their comparative quality positions.

1.2 Related Literature

The present paper is related to the literature in network externality, vertical differentiation, and information goods. Compared with conventional markets, markets with network externalities (also called “network markets”) are well known for their eccentricities: both market history and consumer expectations about future are crucial to network formation (Arthur 1989, Farrel and Saloner 1986, and Katz and Shapiro 1985, 1986). These idiosyncrasies of network markets tend to complicate firms’ competing strategies. For example, firms are more willing to offer their products at below marginal costs to seek an installed-base advantage (“predatory pricing”)(Besen and Farrell 1994). Vendors are often able to acquire additional market leverage via offering a system of related products, e.g. hardware and software, and document viewer and editor (the so-called “systems competition”) (Katz and Shapiro 1994). The present paper explores the intrinsic optimality of product versioning in the context of network externalities: the firm may offer a low-end version (possibly for free) to expand its product network and enhance the value of its high-end version.

In models of vertical differentiation, all consumers prefer the product of the highest quality but differ in their willingness to pay (Mussa and Rosen 1978, Gabszewicz and Thisse 1979, Shaked and Sutton 1982, Gabszewicz et al 1986, Salant 1989). Mussa and Rosen (1978) first formalize the general notion that offering quality-differentiated products serves to discriminate against heterogeneous consumers. As they also point out, however, the firm need not segment its market completely and may "bunch" a group of consumers of different tastes to the same product under certain conditions. In a simple and elegant model, Shaked and Sutton (1982) show that firms can alleviate price competition by differentiating their products. In this literature, the most common consumer utility function involves constant marginal willingness to pay for quality (also see Moorthy 1988 and Tirole 1988, besides the papers just mentioned), which is adopted in the current paper. Since we address the impacts of network externalities on market segmentation in a vertical setting, this present paper also connects these two lines of research on network externality and vertical differentiation.

The extant research on information goods has examined network externalities in software, but has not addressed their impacts on product differentiation. Because of the network-expanding side effect of illegitimate copies, no protection can be the best policy against software piracy (Conner and Rumelt 1991). Even though the pirate copies serve a screening role of separating the plagiarizers from the purchasers, pirating entails additional costs including legal liabilities and differs from adopting a quality-degraded free version. Brynjolfsson and Kemerer (1996) empirically test the benefits that a software vendor can extract from its product network. They show that products with larger installed bases or following the market standard can claim higher prices.

The Internet has opened new possibilities for distributing and selling information goods, which have attracted further research interests (e.g. Bakos and Brynjofsson 1999, 2000, Dewan *et al*. 2000, and Jain and Kannan 2002). Bakos and Brynjofsson (1999) show that bundling large numbers of unrelated information goods can be much more profitable than selling them separately. Note that, bundling is a different price-discrimination mechanism than vertical differentiation, as the bundle size is not equivalent to the notion of product quality.

1.3 Contributions of this Paper

Prior research by Jones and Mendelson (1998) and Bhargava and Choudhary (2001) are instrumental in pointing out the role played by the cost structure of information goods—marginal costs are constant and independent of quality—in their market segmentation. Because many important information goods demonstrate fairly strong network effects, the present paper aims to illustrate that presence of externalities makes a crucial difference in the firm's versioning strategy.

The contribution from this paper is multifold. First, we show that presence of network externalities restores the optimality of market segmentation: the multi-product firm should offer two versions of distinct qualities instead of one. Intuitively, the firm now has an incentive to extend the length of its product line to fully exploit the network benefits. This indicates that, in the presence of network externalities, a vendor of information goods may benefit from a moderate amount of product proliferation. Our findings thus appear consistent with the popular practice of offering quality-differentiated versions among vendors of information goods. Even though our current model does not consider the fixed costs of product development, the number of quality levels derived in this paper serves as an upper bound on the length of the product line when such development costs are taken into account.

Second, the low-end version should be priced below marginal cost under very general conditions. These two versions therefore appear to serve distinct purposes: the low-end version mainly expands the product network and the high-end version is the primary revenue generator. To some extent, this explains the motive for many firms to offer a free low-end version and a priced premium version simultaneously: the free low-quality version is essential for achieving maximum market coverage and enhancing the appeal of the high-end version.

Lastly, this paper also considers firm's versioning strategies in competitive scenarios. When two firms produce compatible products and share the same network, we show that competition may reduce their incentive to price discriminate through product line extension, as neither can solely capture the entire benefits from network expansion.

The rest of the paper is planned as follows. A model is presented in Section 2. Section 3 examines the optimal versioning and pricing strategies of a monopolist and provides empirical evidence. Firms' market segmentation when facing competition is analyzed in Section 4. Section 5 discusses the limitations to the model, the robustness and implications of our results and points out future research directions. The Appendices contain a notation table and a proof omitted in the text.

2 Model

2.1 The Product's Cost Structure

The marginal cost of this product is assumed constant and independent of quality. We further normalize the marginal cost to zero without loss of generality. In our one-period, static model, there is no R&D and the available qualities of each firm are assumed fixed (even though firms may certainly seek quality improvement in multi-period settings). One may regard the costs of product development as being sunk. Therefore, the focus of this paper is to determine the optimal *structure*, instead of the *positioning*, of a product line in the presence of network externalities.

2.2 Consumer Preferences and the Product's Intrinsic Utility

In the one-period economy, each consumer has a unit demand for the information good subject to her reservation utility, which consists of two components. One is the product's *intrinsic utility*, the value generated by its inherent features, and the other the *network utility*, the value generated by the product's network. A consumer of type θ obtains an intrinsic utility $\theta \cdot s$ from a product of quality s, where θ is the consumer's constant *marginal* willingness-to-pay for quality. Consumers are uniformly distributed on $[-A, 1]$ with density 1, where A is a finite positive number. Such a distribution of consumer preferences is analogous to that of Katz and Shapiro (1985). Since we normalize the product's constant marginal cost to zero, the negative domain of the distribution simply stands for those with below-cost valuations toward the product. This negative domain allows us to focus on the market-not-covered case and is not essential for obtaining any key results. Clearly, in the absence of externality, those in the negative domain would never adopt this product, but they may purchase when the product also has network values.

2.3 The Product's Network Utility

Since we consider a product with externalities, its product network also generates value for consumers. Specifically, network externality increases each consumer's taste by γQ, where Q is the network size and γ is the *externality intensity* and reflects the increment in consumers' willingness to pay when an additional user joins the network. Since γ measures the strength of network effects, it may vary according to the nature of the product. For example, online communities typically have stronger network externalities than regular, non-interactive contents. Therefore, when purchasing a product of quality s at price p, consumer θ obtains net utility $(\theta + \gamma Q)s - p$, where $\theta \cdot s$ is the product's intrinsic value and γQs its network value.

In markets of homogeneous goods, the network value of a product often depends on only its network size (e.g., Katz and Shapiro 1985). In markets of heterogeneous goods, however, the network value of the product may also depend on its inherent features (e.g. Farrell and Saloner 1986). In particular, in a vertically differentiated market, as we examine here, the product's network value often depends on *both* its quality *and* the network size. For example, a higher-quality piece of software such as word processors, spreadsheets, and multimedia programs generates greater network value by allowing its users to share documents with enriched features. An online community composed of expert members conceivably produces more insightful content than a community of amateurs. Certain interfacing tasks (e.g. exchanging large files) feasible for users with faster Internet connections may become less convenient or even infeasible between users with slower connections. Advanced features in email such as auto reply and spelling checkers help convey an image of being polite and considerate. In the same network, therefore, a higher quality product has both higher standalone and network values than a lower quality product (see Figure 1). The quality-dependent network utility function (γQs) is not crucial for obtaining our core result on market segmentation. One can readily verify that, under the usual quality-independent treatment on network utility, the optimality of market segmentation still obtains.

Since a product of too little intrinsic use may become less compatible with the other products and thus mitigate its network utility, we impose a lower bound $\underline{s}$ on quality. We also impose an upper bound $\overline{s}$ on quality, reflecting the state-of-the-art in this information good. In the one-period economy, a monopolist naturally makes compatible products to take full advantage of the network benefits. We assume that the two firms in a duopoly also make compatible products. Therefore the network size Q can be conveniently measured by the total unit sales.

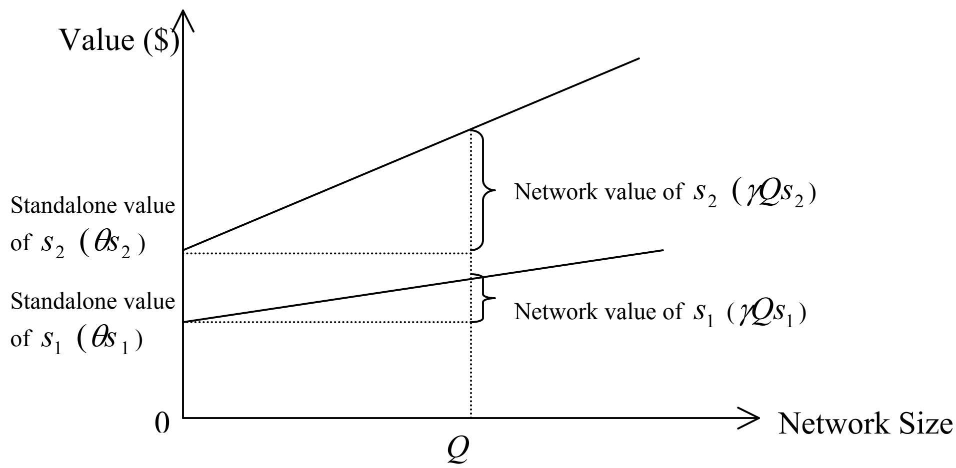

Figure 1. The standalone and network values of products s_2 and s_1 ($s_2 > s_1$) for consumer θ.

2.4 The Solution Concept

The available product qualities of each firm are common knowledge. Our solution concept is the so-called Fulfilled Expectations Equilibrium, in the sense that at equilibrium the network size is exactly as anticipated by consumers prior to their purchases. Each firm announces its prices first (the two firms in a duopoly announce their prices simultaneously). Rational consumers then form identical expectations regarding the ultimate network size and determine whether to purchase, and if so, which product to purchase. Therefore, firms follow a Stackleberg strategy *vis-à-vis* consumers, and the two firms in a duopoly follow Nash price-setting strategies *vis-à-vis* each other.

3 Market Segmentation in a Monopoly

3.1 The Monopolist's Versioning Strategy

Consider a monopolist offering N ($N \geq 2$) compatible products of qualities s_1, s_2, …, and s_N ($\underline{s} \leq s_1 < s_2 < ... < s_N \leq \bar{s}$) at prices p_1, p_2, …, and p_N respectively. Denote θ_k as the consumer indifferent between purchasing s_k and s_{k-1} when $k > 1$, and θ_1 as the consumer indifferent between purchasing s_1 and making no purchase. We thus have

$$\theta_1 s_1 + \gamma s_1 Q - p_1 = 0, \tag{1}$$

and

$$\theta_k s_k + \gamma s_k Q - p_k = \theta_k s_{k-1} + \gamma s_{k-1} Q - p_{k-1}, \quad \text{for } 2 \leq k \leq N, \tag{2}$$

where Q is the network size or total sales of all N products.

At equilibrium the network size must satisfy

$$Q = 1 - \theta_1. \tag{3}$$

From equations (1) and (3), we have

$$Q = \frac{s_1 - p_1}{(1-\gamma)s_1}. \tag{4}$$

From (1), (2) and (4), we then have

$$\theta_1 = \frac{p_1}{s_1} - \gamma Q = \frac{p_1}{s_1} - \frac{\gamma(s_1 - p_1)}{(1-\gamma)s_1}, \text{ and} \tag{5}$$

$$\theta_k = \frac{p_k - p_{k-1}}{s_k - s_{k-1}} - \gamma Q = \frac{p_k - p_{k-1}}{s_k - s_{k-1}} - \frac{\gamma(s_1 - p_1)}{(1-\gamma)s_1}, \qquad \text{for } 2 \leq k \leq N. \tag{6}$$

It is readily verified that the single-crossing property of consumer utility is maintained within the entire domain of consumer tastes: for any given product quality, the valuation by a consumer of a higher θ lies strictly above that by a consumer of a lower θ. Consequently, consumers with $\theta \geq \theta_k$ ($1 \leq k \leq N$) prefer product s_k to any lower quality products, and consumers in $[\theta_k, \theta_{k+1})$ will purchase s_k, where $\theta_{N+1} = 1$. Since consumer distribution has density 1, the unit sales of product s_k are $\theta_{k+1} - \theta_k$. The monopolist's problem is formulated as

$$\underset{p_1,\ldots,p_N}{Max} \quad \sum_{k=1}^{N} p_k(\theta_{k+1} - \theta_k), \tag{7}$$

where $\theta_{N+1} = 1$ and the θ_k's ($1 \le k \le N$) are given by (5) and (6). For tractability, we make the following assumption on externality intensity γ:

ASSUMPTION 1. $\gamma < \dfrac{2\sqrt{\underline{s}}}{\sqrt{\underline{s}} + \sqrt{\bar{s}}}$.

Under this assumption, the second-order condition of (7) is satisfied, as (7) is a quadratic function of the prices and its value approaches minus infinity when the Euclidean norm $\| (p_1, p_2, \ldots, p_N) \| \to \infty$. The first-order conditions of (7) with respect to p_N, …, p_1 are

$$1 - \frac{2(p_N - p_{N-1})}{s_N - s_{N-1}} + \frac{\gamma(s_1 - p_1)}{(1-\gamma)s_1} = 0, \tag{8}$$

$$\frac{p_{k+1} - p_k}{s_{k+1} - s_k} - \frac{p_k - p_{k-1}}{s_k - s_{k-1}} = 0, \quad \text{for } k = 2, \ldots, N-1, \tag{9}$$

and

$$\frac{2(p_2 - p_1)}{s_2 - s_1} - \frac{2p_1 - \gamma s_1 + \gamma p_N}{(1-\gamma)s_1} = 0 \tag{10}$$

respectively.

With equations (4) to (6), equations (8) to (10) can be rewritten as

$$1 - 2\theta_N - \gamma Q = 0 \tag{11}$$

$$\theta_{k+1} - \theta_k = 0, \text{ for } k = 2, \ldots, N-1, \tag{12}$$

$$2\theta_2 - 2\theta_1 - \frac{\gamma(s_1 + p_N)}{(1-\gamma)s_1} = 0. \tag{13}$$

Analyzing the system of first-order conditions (11) to (13) turns out to be a shortcut for determining the firm's quality choice.

Proposition 1. *With network externality (*$\gamma > 0$*), the monopolist will sell products* s_1 *and* s_N.

Proof: From (11) to (13), we have

$$\theta_1 = \theta_2 - \frac{\gamma(s_1 + p_N)}{2(1-\gamma)s_1} < \theta_2 = \theta_3 = ... = \theta_N = (1-\gamma Q)/2 < 1.$$

Therefore, the multi-product monopolist only sells s_1 and s_N, but none of the intermediate products s_2, …, s_{N-1}. **Q.E.D.**

Corollary 1. *Absent externality, the monopolist only sells the top quality product* s_N.

Proof: Setting $\gamma = 0$ in equations (11) to (13), we observe that $\theta_1 = \theta_2 = ... = \theta_N < 1$. **Q.E.D.**

Corollary 1 says that, in markets without network effects, bunching consumers of all tastes to the top quality product is optimal. The underlying rationale is that, at the same marginal cost, any lower-quality product would compete with the top quality good so severely as to reduce the firm's profits. This is precisely the no-segmentation result of Jones and Mendelson (1998) and Bhargava and Choudhary (2001).

Market segmentation by a monopolist has also been examined by Gabszewicz et al (1986). They show that the firm sells the maximum number of products if the range of consumer income is broad enough relative to the feasible quality range, but sells only the top quality product if the range of income is relatively narrow. The difference between their result and our Corollary 1 above is driven by the fact that they consider a *natural* monopolist who always covers the entire market (therefore its market size is fixed) to preclude potential rivals, while in the present paper the firm can choose the size of the market to serve.

Proposition 1 is the core result of this paper. With network externality, the firm segments the market by adding a product of the lowest available quality. Presence of network externality has therefore restored the optimality of second-degree price discrimination in a situation where it would be sub-optimal otherwise. Intuitively, the firm now has extra incentives to extend its product line. Offering the low-end product expands the size of the network and thus increases the network utilities of the high-end product, allowing the firm to extract more surplus. It is precisely this complementary effect between the two compatible products that makes market segmentation optimal. Furthermore, the two versions should be maximally differentiated to best contain cannibalization.

A further question then arises: when network externality is present, why does the monopolist offer only two, but not more (three, four…), distinct versions? It appears that two versions are sufficient for exploiting the network benefits. By manipulating the price of the low-end product, the firm already gains full control over its network size (see (4)). Adding more intermediate goods only exacerbates cannibalization but does not help further expand the network. Notice, Proposition 1 is quite robust in the sense that it holds for any positive externality intensity γ, but is not sensitive to its specific magnitude.

We proceed to determine the firm's optimal prices. With Proposition 1, we can reduce problem (7) into one with only two products: s_1 and s_N. Denote their prices as p_l and p_h respectively. The first-order conditions of this reduced problem are (by replacing s_{N-1} and p_{N-1} in (8) with s_1 and p_1, and replacing s_2 and p_2 in (10) with s_N and p_N respectively):

$$1 - \frac{2(p_N - p_1)}{s_N - s_1} + \frac{\gamma(s_1 - p_1)}{(1-\gamma)s_1} = 0$$

$$\frac{2(p_N - p_1)}{s_N - s_1} - \frac{2p_1 - \gamma s_1 + \gamma p_N}{(1-\gamma)s_1} = 0 .$$

Solving these two equations simultaneously gives the optimal prices:

$$p_1 = \frac{[(2-\gamma)s_1 - \gamma s_N]s_1}{(2-\gamma)^2 s_1 - \gamma^2 s_N},$$

$$p_N = \frac{2(1-\gamma)s_1 s_N}{(2-\gamma)^2 s_1 - \gamma^2 s_N}.$$

The firm's profits can then be found:

$$\pi = \frac{s_1 s_N}{(2-\gamma)^2 s_1 - \gamma^2 s_N}.$$

Proposition 2 shows that, under certain conditions on the externality parameters, the low-end product should be priced below its marginal cost.

Proposition 2. *A)* ***(Below-Cost Pricing)*** *The monopolist prices the low-end product s_1 below its marginal cost ($p_1 < 0$) when $\gamma > \frac{2s_1}{s_1 + s_N}$;*

B) ***(Comparative static)*** *As γ increases, p_1 decreases and p_N increases.*

Proof: A). Under Assumption 1, the denominator of p_1 is strictly positive, i.e. $(2-\gamma)^2 s_1 - \gamma^2 s_N > 0$. The numerator of p_1 is negative under the stated condition.

B). This part is proved by verifying the signs of the respective derivatives:

$$\frac{\partial p_N}{\partial \gamma} = \frac{2\gamma(2-\gamma)s_1 s_N (s_N - s_1)}{[(2-\gamma)^2 s_1 - \gamma^2 s_N]^2} > 0, \text{ and } \frac{\partial p_1}{\partial \gamma} = \frac{-s_1(s_N - s_1)[(2-\gamma)^2 s_1 + \gamma^2 s_N]}{[(2-\gamma)^2 s_1 - \gamma^2 s_N]^2} < 0.$$

Q.E.D.

According to Proposition 2A, when network effects are sufficiently strong, the monopolist would rather offer its low-end version s_1 at a loss. By doing so, the firm can effectively enlarge its product network so that the extra revenue derived from the high-end version more than offsets the loss incurred on the low-end version. Intuitively, these two products are used for quite distinct purposes: *the low-quality version is primarily a network inflator and the high-quality version primarily a revenue source*. For information goods with fairly strong network effects (e.g., Internet access, software, and online communities), Proposition 2A can therefore explain the simultaneous provision of a priced, premium version and a free, degraded version.

With stronger externalities, the network utilities of both products would increase. This would seemingly imply more pricing power for the firm, allowing it to raise the prices for both products. Surprisingly, the firm adjusts the prices in opposite directions (Proposition 2B). The reason is as follows. When facing stronger externalities, the firm has a greater incentive to promote its product network, and the only means to grow its network without incurring more cannibalization is through lowering the price of the low-end product. A larger network boosts the network utilities of the high-end product, allowing the firm to raise the price of the high-end product and reap more profits. The firm's pattern of price adjustment, therefore, echoes the network-inflating role of the low-end product.

3.2 Empirical Evidence

For a firm with multiple *existing* products, Proposition 1 suggests that the optimal product line consists of two versions of distinct qualities. In reality, vendors of information goods frequently version their products via quality degradation: they develop a high-end version first, and then remove certain advanced features to obtain a low-end version (Denekere and McAfee 1996).

Since our model does not include the fixed costs of product development, the predicted product line structure is likely to be observed where the costs of quality degradation are relatively low or negligible.

Such a two-tier product line structure appears in many categories of information goods available on the Internet. For online services such as Internet access, email, and Web hosting, the Internet Service Providers (ISPs) frequently offer one set of basic services for free but charge a fee for the premium services, where connection speed, storage space, and exposure to ads are the respective major criterion for differentiation. Similarly, online communities such as ezboard.com offer vast amount of free content and services to encourage user participation, but also offer premium contents at a fee. Matching services such as Match.com allow one to post his/her personal profile (this person can thus be approached by others) for free, but require a subscription fee if one wants to approach the others. Quality degradation also exists in varieties of software. TaxACT.com offers its standard home-user tax program for free and the deluxe version at a price. Full-featured computer games are usually priced but the degraded versions are often available as free downloads from the Internet (e.g. those listed under the "Shareware" category at **www.freegamesonline.com**).

When the costs of deriving the low-end version exceed the benefits from an extended network, the firm naturally offers its top quality only. Such examples include operating systems, databases, and Enterprise Resources Planning (ERP) systems, where the costs of quality degradation are substantial due to their tremendous size and structural complexity. Because these products are mainly used by institutional and corporate users, a quantity-based market segmentation approach—site licensing—becomes more practical. The modularized structure of ERP systems also suits them ideally for bundling. Lastly, our vertical-differentiation approach to market segmentation should be distinguished from goldilocks pricing, which argues that a firm should offer three distinct products. Goldilocks pricing is based on the theory of "extremeness aversion" in consumer psychology and is not specific to markets with network externalities (Simonson and Tversky 1992 and Shapiro and Varian 1999).

4 Market Segmentation in a Duopoly

This Section examines firm's market segmentation when competition is present. Consider two firms at unequal quality positions, i.e. one firm's best product quality is greater than the other's. In the one-period economy, the best quality of each firm is assumed fixed, and our focus is to determine the firm's versioning decision given its relative quality position. Purely for the sake of tractability, we assume one firm's product offerings are all strictly superior to those of the other, i.e., we exclude two interleaving product lines. When firms overlap their product lines, the main virtue of spatial models—localized competition—is lost, because competition would arise between each adjacent pair of products of different brands. Furthermore, the space of permuting the firms' offerings becomes infinite when product decisions are endogenous. For these difficulties, multi-product oligopolies with overlapping product lines have not been formally addressed in the literature of vertical differentiation (Champsaur and Rochet 1989).

Without loss of generality, suppose the low-end firm, L, has N products of increasing qualities s_1, s_2, …, and s_N, and the high-end firm, H, has K products of increasing qualities s_{N+1}, s_{N+2}, …, and s_{N+K} (i.e., $\underline{s} \le s_1 < s_2 < ... < s_N < s_{N+1} < s_{N+2} < ... < s_{N+K} \le \bar{s}$). In other words, s_N is the highest quality of firm L and s_{N+K} is the highest quality of firm H. Denote p_i as the price for product i ($1 \le i \le N+K$). Each firm attempts to maximize its profits by pricing its existing set of products appropriately. Since we assume that both firms produce compatible products and thus share the same network, here the network size in the duopoly is still given by

$$Q = \frac{s_1 - p_1}{(1-\gamma)s_1}, \tag{14}$$

just as in a monopoly.

The consumer indifferent between purchasing s_1 and not purchasing is

$$\theta_1 = \frac{p_1}{s_1} - \gamma Q = \frac{p_1}{s_1} - \frac{\gamma(s_1 - p_1)}{(1-\gamma)s_1}, \tag{15}$$

and the consumer indifferent between s_k and s_{k-1} is

$$\theta_k = \frac{p_k - p_{k-1}}{s_k - s_{k-1}} - \gamma Q = \frac{p_k - p_{k-1}}{s_k - s_{k-1}} - \frac{\gamma(s_1 - p_1)}{(1-\gamma)s_1}, \qquad \text{for } 2 \le k \le N+K. \tag{16}$$

The simultaneous pricing game may then be formulated as

$$\text{Firm L:} \qquad \underset{p_1,\ldots,p_N}{Max} \quad \sum_{k=1}^{N} p_k(\theta_{k+1} - \theta_k), \tag{17}$$

$$\text{Firm H:} \qquad \underset{p_{N+1},\ldots,p_{N+K}}{Max} \quad \sum_{k=N+1}^{N+K} p_k(\theta_{k+1} - \theta_k), \tag{18}$$

where $\theta_{N+K+1} = 1$ and the θ_k's ($1 \le k \le N+K$) are given in (15) and (16). The second-order conditions of (17) and (18) are satisfied under Assumption 1.

Transforming the first-order conditions of (17) with equations (14) to (16), we obtain the equilibrium sales for each product of firm L:

$$\theta_{N+1} - \theta_N = \frac{p_{N+1}}{2} \ge 0, \qquad \text{for } k = N, \tag{19}$$

$$\theta_{k+1} - \theta_k = 0, \qquad \text{for } k = 2,\ldots,N-1, \tag{20}$$

$$\theta_2 - \theta_1 = 0, \qquad \text{for } k = 1. \tag{21}$$

Similarly, rewriting the first-order conditions of (18) with (14) to (16) leads to the equilibrium sales for each product of firm H:

$$1-\theta_{N+K} = \frac{1}{2}(1+\gamma Q) > 0, \qquad \text{for } k = N+K, \tag{22}$$

$$\theta_{k+1} - \theta_k = 0, \quad \text{for } k = N+2, ..., N+K-1, \tag{23}$$

$$\theta_{N+2} - \theta_{N+1} = \frac{p_N}{2(s_{N+1} - s_N)} \geq 0, \qquad \text{for } k = N+1. \tag{24}$$

Proposition 3. *Facing high-end competition, the low-end firm offers only one product.*

Proof: From (20) and (21), we see that products $s_1, \ldots, s_{N-1}$ all have zero sales under equilibrium pricing. The only product of the low-end firm that could generate positive sales is s_N (from (19)). This suggests that the low-end firm will never segment its market. **Q.E.D.**

Proposition 3 describes the effect of high-end competition on the versioning strategy of the low-end firm. In the current model, firms L and H make compatible products and share the same product network, and the network utility of a product depends on its quality as well as the network size. At a quality disadvantage, firm L is only able to capture a limited portion of the network benefits. Segmenting the low-end market would lead to a larger product network, but much of the benefits of network expansion would accrue to its high-end competitor H. Such spillover effects in a shared network prevent the low-end firm L from offering more than one product, despite the strength of externality.

We proceed to examine the versioning strategy of the high-end firm H. From (22) to (24), s_{N+K} and s_{N+1} are the only two products of firm H that may generate positive sales (the intermediate products of the high-end firm all have zero sales according to (23)). This suggests that firm H should offer *at most* these two products. Therefore, the remaining question is: Is it more profitable for firm H to offer both s_{N+1} and s_{N+K}, or just s_{N+K} alone?

With Proposition 3 and the above observation, the pricing game in (17) and (18) can be reduced to one where firm L offers s_N only and firm H offers s_{N+1} and s_{N+K}:

$$\text{Firm L: } \underset{p_N}{Max} \; p_N\left(\frac{p_{N+1}-p_N}{s_{N+1}-s_N}-\frac{p_N}{s_N}\right). \tag{25}$$

Firm H:

$$\underset{p_{N+K},p_{N+1}}{Max} \; p_{N+K}\left(1+\frac{\gamma(s_N-p_N)}{(1-\gamma)s_N}-\frac{p_{N+K}-p_{N+1}}{s_{N+K}-s_{N+1}}\right)+p_{N+1}\left(\frac{p_{N+K}-p_{N+1}}{s_{N+K}-s_{N+1}}-\frac{p_{N+1}-p_N}{s_{N+1}-s_N}\right) \tag{26}$$

Solving (25) and (26) simultaneously gives the equilibrium prices:

$$p_{N+K}=\frac{4s_{N+1}s_{N+K}-s_Ns_{N+K}-3s_Ns_{N+1}}{(8-6\gamma)s_{N+1}-2s_N}, \; p_{N+1}=\frac{2s_{N+1}(s_{N+1}-s_N)}{(4-3\gamma)s_{N+1}-s_N}, \text{ and } p_N=\frac{s_N(s_{N+1}-s_N)}{(4-3\gamma)s_{N+1}-s_N}.$$

The equilibrium profits (or revenue) of firm H is

$$\pi_H=\frac{s_{N+K}(4s_{N+1}-s_N)^2-s_Ns_{N+1}(s_N+8s_{N+1})}{4((4-3\gamma)s_{N+1}-s_N)^2}.$$

Firm H conducts versioning only when offering both s_{N+1} and s_{N+K} generates greater profits than offering s_{N+K} alone.

Proposition 4. *When competing with a low-end good s_N, the high-end firm offers two products only if its top quality s_{N+K} is sufficiently superior to s_N, i.e.,*

$$s_{N+K}>\frac{20+3\gamma+\sqrt{400+9\gamma(24+\gamma)}}{48\gamma}s_N.$$

Proof: See Appendix 2.

Therefore, the market segmentation decision of firm H depends on the magnitude of its quality advantage over firm L. When firm H offers a second product (besides its top quality s_{N+K}), reduced product differentiation forces firm L to lower its price, leading to a larger product network and thus greater network utilities for each product. As a result, the unit sales of firm H will increase. In the mean time, however, firm H's profit margin will suffer due to the intensified price competition. Whether the gain in unit sales exceeds the drop in profit margin crucially depends on the quality disparity between the two firms.

In markets with positive externalities, a multi-product monopolist always sells two versions of distinct qualities (Proposition 1). In contrast, market segmentation in a duopoly demonstrates very different patterns: the low-end firm always offers a single quality version, and the high-end firm offers two versions of distinct qualities only when it is at a sufficiently large quality advantage. *Presence of competition may cripple a firm's ability to segment its market, because it can not capture all the benefits from network expansion through unilaterally proliferating its product offerings, but has to bear all the damage caused by cannibalization.* Propositions 3 and 4 jointly have the following corollary as their special case.

Corollary 2. *Without externality ($\gamma = 0$), each firm in the duopoly offers only one product.*

Proof: When $\gamma = 0$, only the top-quality version of firm L is purchased (from (19) to (21)), and the threshold quality in Proposition 4 approaches infinity. **Q.E.D.**

Absent externality, the firms lack the incentive to version their products due to potential cannibalization, just as in the monopoly case.

5 Limitations, Implications, and Future Research

5.1 Modeling Assumptions and the Robustness of Results

As is true with all theoretical studies, our model also employs certain assumptions. The two important ones are: 1) each consumer has a constant marginal willingness to pay (MWP for short) for quality; and 2) the network utility of a product depends on its quality. When each consumer has a *decreasing* MWP for quality, market segmentation can be optimal even absent network externalities (Varian 1997). Even though decreasing MWP for *quantity* is a well-accepted premise in economics, constant MWP for quality is a far more commonly used assumption in the literature on vertical differentiation, due to its simplicity and little loss of generality. In the present paper, this assumption facilitates comparison between firm's versioning strategies with and without network externalities, and thus allows us to benchmark our results with those established by Jones and Mendelson (1998) and Bhargava and Choudhary (2001).

Even though it is natural to assume that the network utility of homogeneous goods only depends on their network size, this treatment need not fit well for quality-differentiated products, as discussed in Section 2.3 of this paper and articulated elsewhere by Farrell and Saloner (1986) and Conner (1995). Nevertheless, it can be verified that our key result—versioning is optimal for the monopolist in the presence of externalities—continues to hold even under this alternative assumption, because the same rationale persists: the user base of the low-end version contributes to the network value of the high-end version. The basic insight revealed through this study is therefore quite robust: *network externalities give the monopolist an incentive to extend the length of its product line to take full advantage of the network effects*.

5.2 Implications for Practices

Our analysis indicates that the optimal versioning of information goods may critically hinge on their network externalities. However, even for products demonstrating pronounced externalities, their versioning decision should still take into account other factors such as the exclusiveness of the network and the costs of versioning. In general, versioning benefits vendors in proprietary networks more than those in shared networks. When a product follows an open standard or is compatible with other competing brands, its vendor may consider scaling back its versioning activities as versioning is less likely to generate the desired benefits. As already discussed in Section 3.2, the desirability of versioning also depends on the associated costs, which are mostly driven by the product's structural complexity. For instance, versioning may not pay off for products with complex internal layouts and millions of lines of source code such as operating systems.

Our work also has implications on packaging and versioning certain information goods with little inherent externalities. The value of some regular contents such as music, news, and other topics of special interests may be enhanced by adding community-type features such as comments by critics, dialogue with experts, and peer discussions, etc. In such cases, the vendors may benefit from building communities around their products and then taking advantage of the resulting network effects through versioning.

5.3 Future Research

We conclude by briefly discussing future extensions to this work. Our single-period model necessarily ignores the inter-temporal aspects of network formation and product improvement. Therefore one extension would be to examine externality's role in providing successive versions with improving qualities in a dynamic setting. Another worthwhile direction is to look at the welfare impacts of market segmentation for information goods, which is not addressed in this paper.

Appendices

Appendix 1: Table of Notations.

A	A positive constant ($-A$ is the lower bound of consumer distribution).
p_i's	Prices.
Q	Network size or total sales of compatible products.
s_i's	Product qualities.
$\underline{s}$	The minimum feasible quality. A constant.
$\bar{s}$	The maximum feasible quality. A constant.
π's	Profits/revenue.
θ	Consumer type or marginal willingness to pay for quality.
θ_k	The consumer indifferent between purchasing product s_k and product s_{k-1}.
θ_1	The consumer indifferent between purchasing s_1 and not purchasing.
γ	Externality intensity, a measure of consumer interdependence.

Appendix 2: Proof of Proposition 4.

We can verify that the equilibrium profit of firm H, π_H, is a single-peaked function of s_{N+1} (the peak occurs when $s_{N+1} = \dfrac{s_N(s_N + 6\gamma)}{24\gamma s_{N+K} - (20 - 3\gamma)s_N}$). Therefore, π_H as a function of s_{N+1} has *at most* one peak within $(s_N, s_{N+K}]$. We can then show that $\left.\dfrac{\partial \pi_H}{\partial s_{N+1}}\right|_{s_{N+K}} < 0$ only when

$$s_{N+K} > \frac{20 + 3\gamma + \sqrt{400 + 9\gamma(24 + \gamma)}}{48\gamma} s_N .$$

Q.E.D.

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