COMPATIBILITY COMPETITION IN THE PRESENCE OF NETWORK EXTERNALITIES

KYOUNGWON RHEE[*]

Dongguk University

A quality level is much often determined ahead of price. In imperfectly competitive markets, quality decisions are known to create the rival's price undercutting, and thus the equilibrium quality level becomes suboptimal. This paper takes a view that a quality level of a product subject to network externalities is positively related to its degree of compatibility to other brands as well as to the size of its own network. It shows that in the presence of network externalities, contrary to the literature, the suppliers tend to provide an excessive degree of compatibility because compatibility provision relaxes subsequent price competition.

1. INTRODUCTION

It is well-known that markets hardly generate an efficient incentive for quality provision in general. Two sources of market inefficiency of quality provision have been identified. One was pointed out by Spence (1975) with a monopoly model. He argued that market failure can occur due to the divergence between consumers' marginal and average valuations of quality. His analysis is that the social planner takes care of the effect of an increase in quality on all consumers, while a profit-maximizing firm considers that only on the marginal consumer. Hence, the social optimum is not easily achieved by the market.

Ma and Burgess (1993) detected the other source of inefficiency of quality provision with a duopoly model and with a linear demand function where the Spence effect is eliminated. Considering the two-stage game in which firms' quality choices precedes price decisions, they note that if a firm arranges a higher quality level, then a rival firm

with a lower quality product tends to set a lower price in order for not losing its market share in the price competition subgame. Thus, they contend that a firm's incentive for quality improvement is dampened by the rival firm's price undercutting behavior which depresses the returns to quality investment, thereby leading to underinvestment. Furthermore, they show that when they choose prices and quality levels concurrently, firms can supply socially efficient quality levels. This is because quality choice is not used strategically to have an effect on price decision.

This paper examines the effect of firm's effort for enhancing the value of a product for consumers on the subsequent price competition, and then compares the market performance for such an effort to the social optimum. In this paper, the market under consideration is subject to network externalities. Since the network size - the number of consumers who purchase a similar product - directly affects a consumer's utility in the presence of network externalities, it can be regarded as a determinant of the value of the product, although it is not exactly the same as the product quality dealt in Spence (1975) and Ma and Burgess (1993).

In particular, the paper takes a view that the size of network enjoyed by consumers is often positively related not only to the network size of its own product but also to that of other products if those products are compatible each other. That is, the higher degree of compatibility yields the higher benefit to consumers. In this sense, a value of a product subject to network externalities relies crucially on degree of compatibility in the industry under consideration.

The issue of compatibility in the presence of network externalities has been the subject of many recent studies. Among them, Farrell and Saloner (1985, 1986), Katz and Shapiro (1985, 1986, 1992), Economides (1989), Chou and Shy (1990), and Choi (1994) discuss trade-off between variety and standardization of the competing networks.

While most articles deal with the polar cases of full compatibility and complete incompatibility, many industries such as software, system integration, and home entertainment are characterized by partial compatibility. A few authors, Farrell and Saloner (1992), Chou and Shy (1993)[1], and De Palma, Leruth, and Regibeau (1999), explicitly introduce partial compatibility when the products are subject to network externalities, and describe the market equilibria.

While the degree of compatibility between the products generating their own networks is exogenously given in the literature, many suppliers like software writers, in reality, choose the degree of compatibility. For instance, in the word processing software industry, Microsoft makes its Word file only imperfectly translated into a WordPerfect file. In the personal computer industry, Apple has MacIntosh computers only run some Windows application software. In the ATM networks of banks, consumers with a card issued by a bank cannot enjoy all the services provided by the ATM networks of other

---

[1] Interestingly Chou and Shy (1993) define partial compatibility as the number of supporting services designed for a certain brand that are also compatible with other brands.

banks.[2] Thus, it remains an open question why firms make their products compatible each other in a certain degree, and more interestingly, whether the degree of compatibility provided in a market achieves the social optimum. These are the important issues, because choices of compatibility directly affect a value of a product subject to network externalities when firms cannot choose their network sizes.

For the analysis, I consider a simple duopoly market in which two firms produce the horizontally differentiated goods subject to network externalities. Each firm simultaneously chooses the degree of compatibility of its product at the first stage and then picks the price concurrently at the second stage. With this setting, I observe that the presence of network externalities alone sharpens price competition in the sense that the monopolistic power through product differentiation is diluted. Further, I find that introduction of compatibility can relax such fierce price competition. This is contrary to the common intuition saying that compatibility intensifies price competition by reducing product differentiation.

To see this, suppose that there is no compatibility, implying that there is the maximal differentiation of the products in the horizontal sense. Since a value of a product is directly affected by the market share of the product, consumers wish to purchase the product with the bigger network size for not being stranded in a minor network, other things being equal. In other words, consumers are more sensitive to the changes in price which affect the market shares than in the absence of network externalities. When the products are compatible, however, consumers can reap some benefit from the other network size. This implies that they are not as much worried about being stranded in a minor network as with no compatibility. This in turn makes consumers less sensitive to the price change than with no compatibility. In addition, I find that a firm's provision of compatibility induces not only an increase of its own price but also that of rival firm's price. The latter effect arises because unlike the case of no compatibility, a firm's provision of compatibility imposes the importance on the network size of the competing brand, and because prices are strategic complements.

From the perspective that provision of compatibility directly increases a value of a product for consumers, it is closely related to quality enhancement of a product. The price-enhancing effect created by provision of compatibility is in stark contrast to the literature on quality choices stating that a firm's quality enhancement is counteracted by the rival's price-undercutting reaction in the subsequent price game. Unlike the literature on product differentiation suggested, this result implies that when a market is subject to network externalities, relaxing price competition can be attained not by market segmentation nor by product differentiation but by making consumers not locked in a network so that they can share the benefit from other networks.

Due to the price-enhancing effect of provision of compatibility, welfare analysis tells us that firms arrange an excessive degree of compatibility, although provision of

---

[2] Matutes and Padilla (1994) explored the incentives of banks for sharing the ATM networks.

compatibility is costly. This is because provision of compatibility by the social planner does not create the price-enhancing effect. Since firms' provision of compatibility is interpreted as quality improvement of their products, this inefficient result supports Ma and Burgess (1993) in that the sequential choices of quality and price is another source of inefficiency, but is obtained in a contrary way to Ma and Burgess (1993) who argue that quality improvement leads to price cuts from the rival firm, thereby resulting in underinvestment.

The paper is organized as follows. Section 2 describes the model. Section 3 then yields the equilibrium price. Section 4 compares the equilibrium degree of compatibility with the social optimum. Section 5 concludes.

2. THE MODEL

Consider a duopoly market in which two firms, A and B, produce differentiated products. Throughout the paper, I use a symmetric model where firms have identical cost structure. Each firm may make its product (partially) compatible with the rival's brand. In particular, firm $i \in \{A, B\}$ can choose the degree of compatibility $\alpha_i \in [0, 1]$ where 0 stands for perfect incompatibility, and 1 represents full compatibility. However, provision of compatibility is costly, in that each firm pays $C(\alpha_i)$ for choosing α_i with $C'(\cdot) > 0$, $C''(\cdot) > 0$, $\lim_{\alpha_i \to 0} C'(\alpha_i) = 0$, and $\lim_{\alpha_i \to 1} C'(\alpha_i) = \infty$. The production cost of each firm is affected by the degree of compatibility, for example, through the fees of patents. The total cost of producing a quantity Q with α_i for firm i is $\sigma(\alpha_i)Q + C(\alpha_i)$, where $\sigma(\alpha_i)$ is the unit cost of the good with the degree of compatibility α_i, and is characterized as $\sigma'(\cdot) > 0$, $\sigma''(\cdot) > 0$, $\lim_{\alpha_i \to 0} \sigma'(\alpha_i) = 0$, and $\lim_{\alpha_i \to 1} \sigma'(\alpha_i) = \infty$. Furthermore, it is assumed that $\sigma(0) = C(0) = 0$. The cost function implies that for each firm, higher degree of compatibility requires both higher marginal and fixed costs, and that two products are assumed to be technologically impossible for each firm to achieve the complete compatibility.

There is a continuum of consumers uniformly distributed on a line of length 1. Each consumer buys one unit of any good. The firms' products are subject to network externalities for consumers. Thus, consumer's preference for a good consists of two components: stand-alone component and network component. A consumer indexed by $\theta \in [0, 1]$ receives $a\theta$ for the stand-alone component if he purchases from firm A, and $a(1 - \theta)$ if he buys from firm B. θ can be interpreted as a consumer's preference for the good produced by firm A over the one by firm B. a is assumed to be sufficiently large so that all consumers will buy one unit of a good produced by either A or B. Let X_i denote the size of the network associated with the good produced by firm i. Then, from the network component, a consumer reaps λX_i if he

purchases from firm i. λ measures the importance of network benefits. Note that as long as the two products are (partially) compatible, X_i consists not only of the number of consumers purchasing from firm i, but also of some fraction of those buying from the other firm j. The latter depends on α_i, the degree of compatibility chosen by firm i. Denote by Q_i the number of consumers who buy from firm i. Then, the size of network generated by product i is given by $X_i = Q_i + \alpha Q_j$, where $j \neq i \in \{A, B\}$. Note also that provision of compatibility benefits consumers in that it enhances consumer's utility level through network component.

Suppose that firm i imposes p_i for the price of its product. Furthermore, assume that consumers correctly conjecture the network sizes related to the products when deciding from which firm they purchase. Then, a consumer of type θ gains $u(X_A, p_A; \theta) = a\theta + \lambda X_A - p_A$ if he purchases from firm A, and reaps $u(X_B, p_B; \theta) = a(1 - \theta) + \lambda X_B - p_B$ if he purchases from firm B, where $a > \lambda \geq 0$.[3]

The sequence of events is as follows. At Date 1, each firm chooses the degree of compatibility, α, simultaneously. At Date 2, the firms pick their own prices at the same time. Finally, at Date 3, consumers purchase a product from either of the firms. The firms do not discount their expected profits. The subgame perfect equilibrium is adopted, and thus backward induction will be used for the analysis.

A BENCHMARK

As a benchmark, the socially optimal degree of compatibility will be found. Suppose that the social planner can explicitly enforce the degree of compatibility and the market share of each firm. Since technology and consumers preferences are symmetric, it is optimal to let each firm serve a half of all consumers. Then, the socially optimal degree of compatibility in a symmetric sense, $\alpha^*(\lambda)$, maximizes the sum of utilities of consumers served by each firm less the cost of (partial) compatibility provision:

$$\alpha^*(\lambda) \in \arg\max_\alpha \int_0^{\frac{1}{2}} \left[a(1 - \theta) + \frac{1}{2}\lambda(1 + \alpha) \right] d\theta + \int_{\frac{1}{2}}^1 \left[a\theta + \frac{1}{2}\lambda(1 + \alpha) \right] d\theta$$
$$- \sigma(\alpha) - 2C(\alpha),$$

where given λ, $\alpha^*(\lambda)$ satisfies

$$\lambda = 4C'(\alpha^*) + 2\sigma'(\alpha^*). \tag{1}$$

---

[3] This assumption implies that consumers value the stand-alone component more than the network sizes.

Note that (1) implies that the social planner allows to choose a certain degree of compatibility, i.e., partial compatibility, if $\lambda > 0$, and that the socially efficient degree of compatibility increases in λ.

3. PRICE COMPETITION

With the result of the Date 3 consumer choice game, the demand function that firm i faces can be derived. Under the assumption that consumers correctly expect the network sizes while making a decision where to buy between the firms, let $\hat{\theta}(X_A, X_B, p_A, p_B)$ define the index of the consumer who is just indifferent between buying from firms A and B for $|\lambda(X_B - X_A) + p_A - p_B| \leq a$. This assumption means that the market is fully covered by the two firms. Then,

$$\hat{\theta}(X_A, X_B, p_A, p_B) = \frac{1}{2} + \frac{\lambda(X_B - X_A) + p_A - p_B}{2a}. \tag{2}$$

In equilibrium, the consumers indexed by $\hat{\theta}(X_A, X_B, p_A, p_B)$ buy from firm B, and the rest of the consumers purchase from firm A. From the definition of X_i and $\hat{\theta}(X_A, X_B, p_A, p_B)$, for $|\lambda(X_B - X_A) + p_A - p_B| \leq a$, the demand function firm i faces is derived by

$$Q_i(p_i, p_j, \alpha_i, \alpha_j; \lambda) = \frac{a - \lambda + p_j - p_i + \lambda\alpha_i}{2(a - \lambda) + \lambda(\alpha_i + \alpha_j)}, \quad \text{where} \quad i \neq j \in \{A, B\}. \tag{3}$$

Now consider the Date 2 pricing game by the firms. Given α_i and α_j, firms simultaneously choose their prices to maximize their own profits. Firm i's profit function is $\pi_i = [p_i - \sigma(\alpha_i)] \cdot Q_i(p_i, p_j, \alpha_i, \alpha_j; \lambda) - C(\alpha_i)$. Taking the derivative of firm i's profit function with respect to p_i, we can obtain price reaction functions. Then, the unique equilibrium prices charged by firm A and B are respectively given by

$$p_A^{**}(\alpha_A, \alpha_B; \lambda) = (a - \lambda) + \frac{1}{3}[2\sigma(\alpha_A) + \sigma(\alpha_B)] + \frac{1}{3}\lambda(2\alpha_A + \alpha_B), \tag{4}$$

$$p_B^{**}(\alpha_A, \alpha_B; \lambda) = (a - \lambda) + \frac{1}{3}[2\sigma(\alpha_B) + \sigma(\alpha_A)] + \frac{1}{3}\lambda(2\alpha_B + \alpha_A). \tag{5}$$

The equilibrium prices of (4) and (5) describe the effect of network externalities as well as that of provision of compatibility on price competition. The first parenthesis of the right hand side of both (4) and (5) tells us that price competition in the market subject to network externalities is severer than that in the non-network externality related market. It shows clearly that as long as $\alpha_i < 1$, the equilibrium prices strictly decrease in λ, which implies that the higher the consumers value the network component, the more intense price competition is.

To see this, suppose that there is no compatibility, $\alpha_i = \alpha_j = 0$. Since a consumer's utility level of a product is directly affected by the market share of the product, consumers wish to purchase the product with the bigger network size for not being stranded in a minor network, other things being equal. Moreover, since the changes in prices affect the network sizes, consumers are more sensitive to the latter as the network benefit to consumers is more important. According to (3), it is easily seen that the demand function firm i faces is more elastic to price as the parameter measuring the network importance, λ, is bigger.[4] Consequently, price competition relaxed through the maximal degree of horizontal differentiation is intensified when the market is subject to network externalities. Note that the result of Bertrand competition is obtained as a limiting case when $\lambda \to a$, even in the maximal degree of horizontal differentiation between the products. This result explains, for example, why almost free to use are the internet portal services in which network externalities are known to be much significant.

The result obtained by (4) and (5) is contrary to the common intuition saying that compatibility intensifies price competition by reducing product differentiation. Put it differently, (4) and (5) tell us that provision of compatibility of the products can dampen such fierce price competition driven by network externalities.[5] There are two channels for relaxing price competition through provision of compatibility as follows.

The terms with the second parenthesis of both (4) and (5) characterize the increased marginal cost effect created by each firm's choice of degree of compatibility. Since the equilibrium price of a firm is positively affected by its own marginal production cost as well as by that of its rival firm, a higher degree of compatibility chosen by a firm raises not only its own equilibrium price but also that of the rival firm. This is because a higher degree of compatibility requires a higher marginal production cost and because the price reaction functions are strategic complements.

The terms with the third parenthesis of both (4) and (5) depict the network externalities effect generated by provision of compatibility. The reason why this effect

---

[4] For $\alpha = 0$, the price elasticity of demand for firm i, $\varepsilon_i = -(dQ_i/Q_i)/(dp_i/p_i)$, is reduced to $\varepsilon_i = p_i/(a - \lambda + p_j - p_i)$. Thus, as λ is bigger, the demand for a firm is more elastic to its price.

[5] Farrell and Saloner (1992) made a similar point with the model in which consumers can purchase a converter which generates the imperfect compatibility between the competing networks.

can help the firms raise their prices is as follows. When the competing brands are (partially) compatible, consumers can reap some benefit from the other network size. This implies that consumers are not as much worried about being stranded in a minor network as with no compatibility. This in turn makes consumers less sensitive to the changes in prices than without compatibility. It is easily checked from (3) that the demand function for firm i gets less elastic to price as firm i chooses a higher degree of compatibility is higher.[6]

More importantly, the terms with the second parenthesis of (4) and (5) also present that a firm's provision of compatibility induces not only an increase of its own price but also that of rival firm's price. In particular, the latter effect arises because unlike the case of no compatibility, a firm's provision of compatibility imposes the importance on the network size of the competing brand. The second parenthesis of (4) and (5) imply that by providing compatibility, a firm has less incentive to steal the rival's business than without compatibility, therefore can charge a higher price than without compatibility. The intuition behind this is as follows.

Provision of compatibility increases the value that consumers impose on a product, because it can enlarge the network size of a product, which consumers are concerned about while deciding from which to purchase. Consumer's willingness to pay increases in the degree of compatibility. Thus, a firm has an incentive to set a higher price with compatibility than without it.

(4) and (5) also say that when a competing brand j is compatible with a product i, firm i can charge a higher price than otherwise, although it does not make its product compatible with the product j. As discussed above, firm j's provision of compatibility makes the demand of the competing brand less elastic to the changes in its price, thereby increasing firm j's price. This can raise firm i's demand, although firm j's provision of compatibility reduces it directly. Moreover, the price increase of product j associated by firm j's provision of compatibility positively affects the price of product i through strategic complements.

The same effects can be illustrated alternatively by writing the equilibrium prices (4) and (5) in terms of price-cost margins.

$$P_A^{**}(\alpha_A, \alpha_B; \lambda) - \sigma(\alpha_A) = (a - \lambda) + \frac{1}{3}[\sigma(\alpha_B) - \sigma(\alpha_A)] + \frac{1}{3}\lambda(2\alpha_A + \alpha_B), \qquad (6)$$

$$P_B^{**}(\alpha_A, \alpha_B; \lambda) - \sigma(\alpha_B) = (a - \lambda) + \frac{1}{3}[\sigma(\alpha_A) - \sigma(\alpha_B)] + \frac{1}{3}\lambda(2\alpha_B + \alpha_A). \qquad (7)$$

---

[6] However, the price elasticity of demand for firm i is not affected by the rival firm's provision of compatibility.

In particular, (6) and (7) tell us that when each firm chooses the same degree of compatibility so that their marginal production costs are the same each other, the price-cost margin can be enhanced solely by provision of compatibility.

It remains one more notable implication that (4) and (5) yield: when a market is subject to network externalities, unlike the literature on product differentiation suggested, relaxing price competition can be attained not by market segmentation nor by product differentiation but by making consumers not locked in a network so that they can share the benefit from other networks. Furthermore, although the paper adopts a horizontal product differentiation model, the result is related to the vertical product differentiation á la Shaked and Sutton (1982), since relaxing price competition can be achieved by a firm's provision of compatibility which gives the direct benefit to consumers by increasing the network size of its product.

Although the network size of a product is not the same as the intrinsic quality of the product, it can be seen that they are related each other in that they affect a level of consumer's utility directly. From that perspective, the result of the paper is in stark contrast to Ma and Burgess (1993) who argue that a firm's quality enhancement is counteracted by the rival's price-undercutting reaction in the subsequent price game, thereby leading to intense price competition and eliminating the demand enhancing effect of an increase in quality. The above results of the paper are summarized in Proposition 1.

Proposition 1. *The equilibrium prices of (4) and (5) strictly decrease in λ unless $\alpha_i = \alpha_j = 1$, but strictly increase in either α_i or α_j for all $\lambda > 0$.*

4.   COMPATIBILITY COMPETITION

Expecting what happens in the price-subgame, firm i chooses α_i maximizing its profit in terms of degrees of compatibility given by

$$\pi_i(\alpha_i, \alpha_j; \lambda) = \frac{\left[(a-\lambda) + \frac{1}{3}[\sigma(\alpha_j) - \sigma(\alpha_i)] + \frac{1}{3}\lambda(2\alpha_i + \alpha_j)\right]^2}{2(a-\lambda) + \lambda(\alpha_i + \alpha_j)} - C(\alpha_i) . \tag{8}$$

In general, the profit function π_i is not concave with respect to α_i. Nonetheless, the appropriate first order conditions still will be necessary at an equilibrium. Consider the symmetric equilibrium in which firms' choices of degree of compatibility and of prices are equivalent and their market shares are a half, respectively. Then, given λ, the symmetric equilibrium degree of compatibility, $\alpha^{**}(\lambda)$, is characterized by Proposition 2.

Proposition 2. *In the game in which firms simultaneously choose degrees of compatibility at the first stage and then prices at the second stage, given λ, the symmetric equilibrium degree of compatibility $\alpha^{**}(\lambda)$ satisfies*

$$\lambda = \frac{12}{5}C'\left(\alpha^{**}\right) + \frac{4}{5}\sigma'\left(\alpha^{**}\right). \tag{9}$$

Two features are notable from (9). One is that in the symmetric equilibrium, the firms have a positive incentive to make their products partially compatible each other, as long as $\frac{1}{2}[a - \lambda + \lambda\alpha^{**}(\lambda)] \geq C(\alpha^{**}(\lambda))$. From the comparison with (1), (9) describes that given λ, $\alpha^{**}(\lambda) > \alpha^{*}(\lambda)$, i.e., the excessive degree of compatibility compared to the social optimum. Figure 1 illustrates the determination of $\alpha^{**}(\lambda)$ and $\alpha^{*}(\lambda)$.
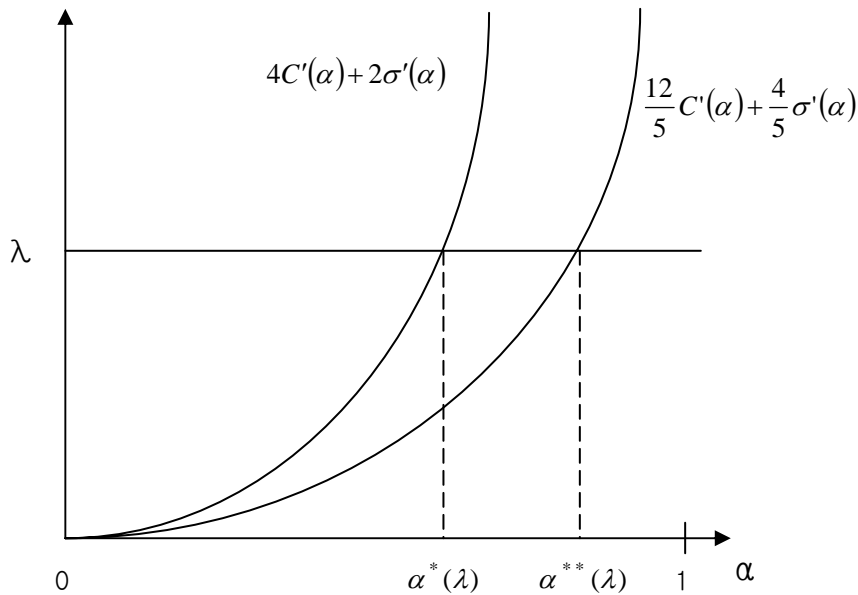
Figure 1.   Equilibrium and Efficient Level of Degree of Compatibility

According to (1) and (9), it is seen that the inefficiency of degree of compatibility stems from the price-enhancing effect of compatibility provision. As discussed in the previous section, the price-enhancing effect arises both from increased marginal cost and from lower price elasticity of demand by provision of compatibility. However, the social

planner does not take into account the price-enhancing effect of compatibility provision, when choosing the degree of compatibility.

This inefficiency result holds even when degree of compatibility of a product is determined separably. Consider a model in which degree of compatibility can be increased by either higher marginal cost, higher fixed cost, or both. Suppose that degree of compatibility is a sum of two parts, i.e., $\alpha = \alpha_1 + \alpha_2$, and that total cost of producing Q units of the good with α degree of compatibility is $\sigma(\alpha_1)Q + C(\alpha_2)$. Then, a firm in this model chooses both marginal and fixed costs to determine degree of compatibility. The socially efficient degree of compatibility, $\alpha^*(\lambda)$, is derived: $\alpha^*(\lambda) = \alpha_1^*(\lambda) + \alpha_2^*(\lambda)$, where $\lambda = 2\sigma'(\alpha_1^*)$ and $\lambda = 4C'(\alpha_2^*)$. In detail, when there is an increase of degree of compatibility, consumers' surplus rises by $\frac{1}{2}\lambda$ from increased network benefit, while the marginal production cost increases by $\sigma'(\alpha)$, and while the fixed cost goes up by $2C'(\alpha)$, respectively.[7]

Since the second-stage price competition equilibrium can be obtained as in (4) and (5) with this model, one can derive the equilibrium degree of compatibility in a similar way. It is straightforwardly verifiable that in the symmetric equilibrium degree of compatibility, $\alpha^{**}(\lambda) = \alpha_1^{**}(\lambda) + \alpha_2^{**}(\lambda)$, where $\lambda = \frac{4}{5}\sigma'(\alpha_1^{**})$ and $\lambda = \frac{12}{5}C'(\alpha_2^{**})$. To see this, first consider the first derivative of firm i's profit function with respect to α_1.

$$\frac{d\pi_i}{d\alpha_1} = \frac{dp_i}{d\alpha_1} \cdot Q_i + \frac{dQ_i}{d\alpha_1}(p_i - \sigma(\alpha_1)) - \sigma'(\alpha_1)Q_i, \tag{10}$$

where $\dfrac{dQ_i}{d\alpha_1} = \dfrac{\partial Q_i}{\partial \alpha_1} + \dfrac{dQ_i}{dp_i} \cdot \dfrac{dp_i}{d\alpha_1} + \dfrac{dQ_i}{dp_j} \cdot \dfrac{dp_j}{d\alpha_1}$.

Then, (10) can be rewritten by

---

[7] Note that the increased consumers' surplus $\frac{1}{2}\lambda$ by allowing compatibility comes from the size of competing network, $\frac{1}{2}$, and the importance of network externalities, λ.

$$\frac{d\pi_i}{d\alpha_1} = \left[\frac{dp_i}{d\alpha_1} \cdot Q_i + (p_i - \sigma(\alpha_1)) \cdot \left(\frac{dQ_i}{dp_i} \cdot \frac{dp_i}{d\alpha_1} + \frac{dQ_i}{dp_j} \cdot \frac{dp_j}{d\alpha_1} \right) \right]$$
$$+ \left[\frac{\partial Q_i}{\partial \alpha_1} (p_i - \sigma(\alpha_1)) - \sigma'(\alpha_1)Q_i \right]. \tag{11}$$

The first bracket of the right hand side of (11) arises from the price-enhancing effect created by provision of compatibility, which does not exist when the social optimum is derived. However, note that the second bracket of the right hand side of (11) is also considered for the socially optimal degree of compatibility. Thus, in the symmetric equilibrium, it is obtained that $\lambda = \frac{4}{5}\sigma'(\alpha_1^{**})$.

Similarly, to see the effect of provision of compatibility on the fixed costs, consider the first derivative of firm i's profit function with respect to α_2.

$$\frac{d\pi_i}{d\alpha_2} = \frac{dp_i}{d\alpha_2} \cdot Q_i + \frac{dQ_i}{d\alpha_2} \cdot p_i - C'(\alpha_2), \tag{12}$$

where $\frac{dQ_i}{d\alpha_2} = \frac{\partial Q_i}{\partial \alpha_2} + \frac{dQ_i}{dp_i} \cdot \frac{dp_i}{d\alpha_2} + \frac{dQ_i}{dp_j} \cdot \frac{dp_j}{d\alpha_2}$.

Then, one can rewrite (12) as

$$\frac{d\pi_i}{d\alpha_2} = \left[\frac{dp_i}{d\alpha_2} \cdot Q_i + p_i \cdot \left(\frac{dQ_i}{dp_i} \cdot \frac{dp_i}{d\alpha_2} + \frac{dQ_i}{dp_j} \cdot \frac{dp_j}{d\alpha_2} \right) \right] + \left[\frac{\partial Q_i}{\partial \alpha_2} \cdot p_i - C'(\alpha_2) \right]. \tag{13}$$

Just like in the previous paragraph, the first bracket of the right hand side of (13) originates from the price-enhancing effect of provision of compatibility, which never arises for finding the social optimum. Hence, in the symmetric equilibrium, $\lambda = \frac{12}{5}C'(\alpha_2^{**})$ is derived.

Given λ, it is easy to see that $\alpha_1^* < \alpha_1^{**}$ and $\alpha_2^* < \alpha_2^{**}$ so that $\alpha^* < \alpha^{**}$. That is, given λ, degree of compatibility in the market is chosen excessively to the social optimum both through marginal cost and through fixed cost. This result is due to the price-enhancing effect created by provision of compatibility, in particular, through the effect of increased marginal cost and the effect of network externalities on price. The result also implies that both of these two effects are valid for the inefficiency of degree

of compatibility.[8]

As Ma and Burgess (1993) point out, the source of this inefficiency is the sequential choice of degree of compatibility and price. To see this, consider a situation in which degrees of compatibility and prices are determined simultaneously so that the choices of degree of compatibility no longer have effects on price choices. Then, firm i 's maximization problem is that

$$\max_{p_i, \alpha_i} \pi_i(p_i, p_j, \alpha_i, \alpha_j; \lambda) = [p_i - \sigma(\alpha_i)] \frac{a - \lambda + p_j - p_i + \lambda \alpha_i}{2(a - \lambda) + \lambda(\alpha_i + \alpha_j)} - C(\alpha_i).$$

The associated symmetric equilibrium price and degree of compatibility are given by

$$p^*(\alpha^*; \lambda) = (a - \lambda) + \sigma(\alpha^*) + \lambda \alpha^*$$
$$\lambda = 4C'(\alpha^*) + 2\sigma'(\alpha^*).$$

It is easy to see that in this game, the symmetric equilibrium degree of compatibility is equivalent to the social optimum,[9] while the equilibrium price is less than that when firms simultaneously choose degrees of compatibility in stage one and then prices in stage two. Thus, it comes to a conclusion that whether or not efficiency of provision of compatibility is achieved relies crucially on whether or not compatibility provision decision affects price.

5. CONCLUSION

The paper takes a view that provision of compatibility is related to quality improvement of product subject to network externalities in that it directly increases a value of a product for consumers. This paper investigates why firms have an incentive to supply compatibility and then compare the degree of compatibility provided in the market with the social optimum. For the analysis, it adopts a model in which in an

---

[8] One may consider a case, for example, Digital Rights Managements, in which the cost of provision of (partial) compatibility is minor. Assuming that the development cost for providing compatibility is positive and dependent upon the degree of compatibility, this case can be correspondent to the model of this paper either where the marginal production cost is 0, i.e., $\sigma(\alpha_i) = 0$, or where it is independent of provision of compatibility. Comparing (9) with (1), the result does not change qualitatively. This implies that as seen from the case of separable cost function, the inefficiency result holds unless provision of compatibility entails any cost at all.

[9] When price and degree of compatibility are chosen simultaneously, the first brackets of the right hand side of (11) and (13) are omitted, since there exists no effect of provision of compatibility on price.

imperfectly competitive market, firms simultaneously choose degree of compatibility at the first stage and then pick price at the second stage. Furthermore, a higher degree of compatibility requires both a higher marginal production cost and a higher fixed cost.

This paper finds that provision of compatibility creates the price-enhancing effect through the increased marginal cost effect and through network externality effect, hereby relaxing price competition. This in turn induces the excessive degree of compatibility compared to the social optimum. In addition, the paper verifies that the inefficiency stems from the sequential choices of provision of compatibility and price.

REFERENCES

Choi, J.P. (1994), "Irreversible Choice of Uncertain Technologies with Network Externalities," *Rand Journal of Economics*, 25(3), 382-401.

Chou, C.F., and O. Shy (1990), "Network Effects without Network Externalities," *International Journal of Industrial Organization*, 8(2), 259-270.

_____ (1993), "Partial Compatibility and Supporting Services," *Economics Letters*, 41(2), 193-197.

De Palma, A., L. Leruth and P. Regibeau (1999), "Partial Compatibility with Network Externalities and Double Purchase," *Information Economics and Policy*, 11(2), 209-227.

Economides, N. (1989), "Desirability of Compatibility in the Absence of Network Externalities," *American Economic Review*, 79(5), 1165-1181.

Farrell, J., and G. Saloner (1985), "Standardization, Compatibility, and Innovation," *Rand Journal of Economics*, 16(1), 70-83.

_____ (1986), "Installed Base and Compatibility," *American Economic Review*, 76(5), 940-955.

_____ (1992), "Converters, Compatibility and the Control of Interfaces," *Journal of Industrial Economics*, 40(1), 9-35.

Katz, M.L., and C. Shapiro (1985), "Network Externalities, Competition and Compatibility," *American Economic Review*, 75(3), 424-440.

_____ (1986), "Technology Adoption in The Presence of Network Externalities," *Journal of Political Economy*, 94(4), 822-841.

_____ (1992), "Product Introduction with Network Externalities," *Journal of Industrial Economics*, 40(1), 55-83.

Ma, C.A., and J.F. Burgess (1993), "Quality Competition, Welfare, and Regulation," *Journal of Economics*, 58(2), 153-173.

Matutes, C., and A.J. Padilla (1994), "Shared ATM Networks and Banking Competition," *European Economic Review*, 38(1), 1113-1138.

Shaked, A., and J. Sutton (1982), "Relaxing Price Competition through Product

Differentiation," *Review of Economic Studies*, 49(1), 3-13.

Spence, A.M. (1975), "Monopoly, Quality, and Regulation," *Bell Journal of Economics*, 6, 417-429.

Mailing Address: Dongguk University, Department of Economics, 26 Pil-dong 3ga, Joong-gu, Seoul, 100-715, Korea. Tel: +82-2-2260-3311, Fax: +82-2-2260-3940. E-mail: krhee@dongguk.edu.