

# Software Compatibility Alters Entry Deterrence\*

KODERA Toshiki

In this paper, we investigate the competition of two firms that adopt partially compatible technologies in the presence of indirect network effects. We show that the two firms change their strategies due to the degree of compatibility under a given set of conditions. The strategies that the incumbent firm can choose are to monopolize the market, deter the entry, or accommodate the entry and exit the market. When the degree of compatibility is relatively high under a given set of conditions, the incumbent firm cannot deter the entrant. Then, the incumbent firm exits the market and the entrant monopolizes. On the other hand, when the degree of compatibility is relatively low under a given set of conditions, the incumbent firm can deter the competitor's entry. The social welfare when the incumbent firm deters the entry is larger than that when two firms compete within a certain degree of compatibility.

## I. Introduction

In the last decade, information technology has progressed dramatically. The Ministry of Internal Affairs and Communications showed that the penetration rate of personal computers was 77.5% in 2004, up from 22.3% in 1996. Nowadays, personal computers have spread to almost all consumers. When consumers purchase a personal computer, they purchase it as a technology that combines hardware with complementary software. The utility of the computer to the consumer depends on the services supported by software. The more varieties of software available along with complementary services, the greater the value of the hardware and its utility to

consumers. Such effects are called indirect network effects.

A great deal of literature has been published on network effects, including the indirect network effects. Previous studies of network effects include Katz and Shapiro (1985) and Farrell and Saloner (1985). Katz and Shapiro (1985) investigated network externalities by which consumers estimate the value of goods when other consumers use compatible goods.<sup>1)</sup> They analyzed the private and social incentives for compatibility based on the presence of network externalities, and demonstrated that socially necessary compatibility is not offered when the private incentives are lower than the social incentives. Farrell and Saloner (1985) analyzed the

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adoption of new technology or standardization. They showed that once technologies and standards are adopted, firms cannot shift to new technologies and better standards.

Among network effects, there are direct network effects as well as indirect network effects. The essence of direct network effects is that consumers increase their willingness to pay for network goods with an overall increase of consumers. Telephones, faxes, e-mails and languages are given as examples of these effects. If the number of consumers purchasing a telephone increases, a telephone network grows and brings a telephone user more utility. In the same way, learning a language allows a people to talk with other people. The more people know and use the language, the more utility there is in learning the language.

In contrast, the essence of indirect network effects is that the variety of complementary goods increases with the wider purchase of the durable goods on which they are based. Indirect network effects are found in the market of consumer electronics such as personal computers, video cassette recorders, CD players and video games. As the number of consumers having CD players increases, the demand for CDs increases. Then, music companies increase the supply and variety of CDs, and consumers find more utility in their CD

player. One of the pioneer works on indirect network effects is Chou and Shy (1990), who looked at the computer industry.<sup>2)</sup> They assume that consumers gain their utility from the variety of software, and software companies have large fixed costs and increasing returns to scale. Then, they show that the variety of software can substitute for network externalities.

Like them, we also focus on the computer industry. We developed a model following Church and Gandal (1996), who assume that a hardware company vertically integrates software companies and that an incumbent technology is incompatible with an entrant technology. Extending their model, we assume that there is a partial compatibility which Chou and Shy (1993) found. The partial compatibility is that a part of one company's software can be run on the other company's hardware. Nowadays most personal computers for home use are sold with some application software: for example, word-processing software, spreadsheet, browser software and audio player. Home computers are either Windows computers or Macintosh computer. Some application software and files of Macintosh run on Windows computers. For instance, we can run Microsoft Word, which is word-processing software, on both Macintosh and Windows computers. However, the latest versions of Internet Explorer,

which is a browser software, only run on Windows computers.

Church and Gandal (1996) show that an incumbent firm forms installed base by committing itself to a variety of software. Then, the incumbent firm chooses strategies for entrants, whereby three types of equilibrium occur. In the first equilibrium, the incumbent will blockade the entry when the fixed costs of software development are relatively small. In the second equilibrium, the incumbent will deter the entry when the fixed costs of software development are moderate. Third, the incumbent will accommodate the entry when the fixed costs of software development are relatively large.

In this paper, we assume that the software of the incumbent firm is partially compatible with the entrant technology. Then, the consumers purchasing the entrant technology can use the software of the entrant and a part of the software of the incumbent firm. We assume that the degree of compatibility of software is common knowledge. Following Church and Gandal, hardware firms integrate software firms vertically, and hence, we solve a multi-stage game. In the first stage, the incumbent firm decides whether or not to exit the market. The incumbent firm commits to the additional varieties of software when the incumbent firm decides to stay in the market. Its

varieties of software become its installed base. In the second stage, the entrant decides whether or not to enter the market, and the entrant commits to the additional varieties of software depending on the degree of compatibility. Thus, the entrant commits to the varieties of software after the incumbent has committed. The entrant can observe the technology of the incumbent and capture the compatibility. However, the incumbent is not compatible with the technology of the entrant because the incumbent decides on software investments beforehand. When the incumbent exits the market and the entrant decides to enter the market, the entrant becomes a monopolist. The opposite is true. Then, the entrant can use the own software because the incumbent's software are not supplied. In the third stage, a hardware price competition occurs among the two firms. Then, consumers decide which hardware they purchase. If either firm monopolizes the market, the monopolist decides a hardware price exclusively. In the final stage, the software price is decided and consumers purchase a technology.

Consequently, there are four types of equilibrium that are brought by the degree of compatibility and the software development costs. The first equilibrium is that monopolized by the incumbent firm. This equilibrium occurs when the software development costs are relatively

small. The second equilibrium is the duopoly equilibrium. This equilibrium occurs when the software development costs are relatively large. The third equilibrium is the deterrence equilibrium. This equilibrium occurs when the software development costs are moderate and the degree of compatibility is relatively low. The last equilibrium is that is monopolized by the entrant. This equilibrium occurs when the software development costs are moderate and the degree of compatibility is relatively high. We find that the welfare of the deterrence equilibrium is inefficient compared with the welfare of the equilibrium that is monopolized by the entrant. However, the welfare when the incumbent firm deters the entry can be better than that when the two firms compete. The main reason is that the variety of software when the incumbent firm deters the entrant is greater than the variety of software when the incumbent firm accommodates the entry.

These results give us a new perspective for investigating the fact. In France, legislators are deliberating on a bill to open the technology of iPod and iTunes Music Store. The iPod is a portable music player developed by Apple Computer. The iTunes Music Store is a music download site also developed by Apple Computer. The iTunes Music Store complements the iPod by supplying many music files to it. There are indirect

network effects in the portable music player market. The greater the iPod sales, the more music files in the iTunes Music Store. Nowadays, the iPod and the iTunes Music Store monopolize this market. The technology of the iPod and iTunes Music Store is incompatible with that of Sony or Toshiba. Sony recently improved its portable music player to play the music files of iPod. However, iPod cannot play the music files of Sony. Thus, the music files of iPod are partially compatible with that of Sony. Therefore, our model with partial compatibility may help to explain the strategies of firms and the policies of government.

Further these results have effects on welfare. Church and Gandal (1996) show that deterrence produces an inefficient welfare when the two technologies are incompatible with each other. In this paper, we show that deterrence does not always decrease the welfare. The deterrence welfare is larger than the welfare when the two firms enter the market with a certain degree of compatibility and certain software development costs. Added to this, when the entrant that has a superior hardware producing technology monopolizes the market, its welfare expands compared to the deterrence welfare with a certain degree of compatibility. Policy makers should thus focus attention on the degree of compatibility and the software

development costs.

The structure of this paper is as follows. Section 2 shows the model assumptions. Section 3 shows the equilibrium price of software. Section 4 shows the equilibrium price of hardware. In Section 5 shows the conditions under which the entrant commits to varieties of software. In Section 6 shows the conditions under which the incumbent firm commits to varieties of software. In Section 7, we derive an equilibrium. In Section 8, we analyze the welfare. Concluding remarks follow in Section 9.

## II. The model

In this section, we assume the structure of the model.

There are two hardware technologies, named  $A$  and  $B$ . We assume that there is horizontal differentiation between hardware  $A$  and  $B$ . Exogenously, the two kinds of hardware lie at each end of a unit line. Suppose that the fixed costs of hardware are  $C_i$ ,  $i = A, B$  and the fixed costs of hardware  $A$  are larger than that of hardware  $B$ :  $C_A > C_B = 0$ . We assume that the marginal costs of hardware  $A$  and  $B$  are equal to zero.

There exists some software to complement each type of hardware. Suppose that the number of varieties of software written for hardware  $i$  is  $n_i$ , with  $n_i$  being a positive real number. We assume that the entrant has partial

compatibility for the software of the incumbent firm. Thus, the hardware of the entrant can run all of the software written for own hardware and some of the software written for the incumbent's hardware. We assume that the exogenously given degree of compatibility of software is  $\theta$ ,  $0 < \theta < 1$ , when the hardware of the entrant can run the software written for the hardware of the incumbent. When the degree of compatibility becomes large,  $\theta$  approaches one. The incumbent does not have partial compatibility for the software of the entrant because the incumbent cannot prepare to be compatible with the software of entrant. We assume that the fixed cost of software development is  $f$ ,  $f > 0$ , and the marginal cost of the software is equal to zero. The fixed costs of software development and hardware are given. The supply of software is perfectly inelastic.

Suppose that consumers purchase one unit of hardware, all of the software developed by the firm that supplies the hardware, and an outside good. The value of the hardware depends on the total varieties of software which can be run on it. As the varieties of software increase, the value of the hardware increases. Consumers receive the network effects  $\beta$ ,  $0 < \beta < 1$ , from the varieties of software that they can use. We assume that consumers gain the basic benefits  $\alpha$ ,  $\alpha \geq 3/2$ , when they consumers purchase both one hardware and the

total varieties of software.<sup>3)</sup> Consumers uniformly distribute on the unit line. The total number of consumers is one. The income of a consumer is  $y$ . The utility functions of a consumer purchasing  $A$  and  $B$  are

$$U_A = \alpha + n_A^\beta + x - t_A, \quad (1)$$

$$U_B = \alpha + n_B^\beta + (\theta n_A)^\beta + x - t_B, \quad (2)$$

where  $t_i$  is the distance of a consumer from hardware  $i$ . We can denote  $t_i = 1 - t_j$  for the length of the line is one. The consumers of firm  $B$  can use all of software  $B$  and a part of the software  $A$  files. Thus, the budget constraint of a consumer is in common

$$\sum_{k=1}^{n_i} \rho_{ki} + x = y - p_i, \quad (3)$$

where  $p_i$  is the price of hardware  $i$ , and  $\rho_{ki}$  is the price of one software of the varieties  $k$  of software run on hardware  $i$ . Substituting Equation (3) for Equation (1) and Equation (2) yields the indirect utility functions for a consumer purchasing  $A$  and  $B$ :

$$V_A = n_A^\beta - \sum_{k=1}^{n_A} \rho_{kA} + \alpha + y - p_A - t_A, \quad (4)$$

$$V_B = n_B^\beta - \sum_{k=1}^{n_B} \rho_{kB} + (\theta n_A)^\beta + \alpha + y - p_B - t_B. \quad (5)$$

The structure of this game is as follows. Each additional variety of

software improves the value of the hardware it runs on. Thus, the varieties of software affect the strategies of firms in the presence of indirect network effects. In the first stage, firm  $A$  decides whether or not to exit. When firm  $A$  stays in the market, firm  $A$  commits to supplying the variety of software.<sup>4)</sup> Firm  $A$  cannot change the varieties of software at a subsequent stage. In the second stage, firm  $B$  decides whether or not to enter. If firm  $B$  decides to enter, firm  $B$  commits to supplying the variety of software depending on the degree of compatibility. Firm  $B$  cannot change the varieties of software at a subsequent stage, either. In the third stage, if firm  $B$  decides to enter, firm  $A$  comes into hardware price competition against firm  $B$ . If firm  $B$  decides not to enter, firm  $A$  behaves as a monopolist. If firm  $A$  exits the market, firm  $B$  becomes a monopolist. Consumers decide the hardware that they will purchase in the next stage. In the fourth stage, software is priced and consumers purchase a technology. We solve this game by backwards induction.

### III. Symmetric equilibrium price of software

Firm  $i$  does not change varieties of software  $n_i$  after having committed. Thus, the supply of software is perfectly inelastic. Consumers purchase all

software that complements hardware  $i$  after having purchased it. In equilibrium, the varieties of software that consumers purchase are equal to the varieties of software that the firm supplies. Differentiating Equation (4) yields the equilibrium price of software

$$\rho_i = \beta n_i^{\beta-1}. \quad (6)$$

Substituting Equation (6) for Equation (4) and Equation (5)

$$V_A = (1-\beta)n_A^\beta + \alpha + y - p_A - t_A, \quad (7)$$

$$V_B = (1-\beta)n_B^\beta + (\theta n_A)^\beta + \alpha + y - p_B - t_B, \quad (8)$$

Equation (7) shows that the benefits of a consumer purchasing technology  $A$  increase when the varieties of software increase. Equation (8) shows that the benefits of a consumer purchasing technology  $B$  increase when the varieties of software or the degree of compatibility increases. When the benefits of purchasing technology  $A$  are equal to the benefits of purchasing technology  $B$ , technology  $A$  and  $B$  are indifferent for a consumer. The market share of technology  $A$  and  $B$  are

$$t_A = \frac{(1-\beta)(n_A^\beta - n_B^\beta) - (\theta n_A)^\beta - (p_A - p_B) + 1}{2}, \quad (9)$$

$$t_B = \frac{(1-\beta)(n_B^\beta - n_A^\beta) - (\theta n_A)^\beta - (p_B - p_A) + 1}{2}. \quad (10)$$

The market share of technology  $i$  increases when its own hardware price depreciates or the hardware price of a competitor increases.

#### IV. Equilibrium price of hardware

This section deals with the determination of the hardware price under the monopoly or duopoly. Suppose that the profit function of firm  $i$  is

$$\Pi_i = (p_i + \beta n_i^\beta) t_i - f n_i - C_i. \quad (11)$$

From Equation (6), the software revenue of firm  $i$  is given by  $\beta n_i^\beta$ .

##### 1. Monopoly

First, we consider the case in which firm  $i$  becomes a monopolist. When firm  $A$  blockades the entry of firm  $B$ , firm  $A$  monopolizes the market. Added to this, when firm  $A$  exits the market, firm  $B$  becomes a monopolist. Suppose that a consumer who is on an edge of the other side gains the same benefits as he would from purchasing outside goods, when he purchase technology  $i$ . From Equation (7), the monopoly price of hardware  $i$  is

$$p_i = (1-\beta)n_i^\beta + \alpha - 1. \quad (12)$$

Substituting the market share of a monopolist,  $t_i = 1$ , and Equation (11) for Equation (12), the profits of firm  $i$  are

$$\Pi_i = n_i^\beta + \alpha - 1 - fn_i - C_i. \quad (13)$$

From Equation (12), the hardware price increases with increasing the varieties of supported software.

## 2. Duopoly

After both firms have committed to supplying some software, they compete in terms of the hardware price. This is the Bertrand competition for hardware price. We assume the condition that  $|(1-\theta_B^\beta)n_A^\beta - n_B^\beta| \leq 3$ .<sup>5)</sup> Maximizing Equation (11) with respect to  $p_A$  and  $p_B$  results in the best reply of firm  $A$  and  $B$

$$p_A = \frac{(1-2\beta-\theta^\beta)n_A^\beta - (1-\beta)n_B^\beta + p_B + 1}{2}, \quad (14)$$

$$p_B = \frac{(1-2\beta)n_B^\beta - (1-\beta-\theta^\beta)n_A^\beta + p_A + 1}{2}. \quad (15)$$

Equation (14) and Equation (15) yield the equilibrium hardware prices:

$$p_A = \frac{(1-3\beta-\theta^\beta)n_A^\beta - n_B^\beta + 3}{3}, \quad (16)$$

$$p_B = \frac{(1-3\beta)n_B^\beta - (1-\theta^\beta)n_A^\beta + 3}{3}. \quad (17)$$

Substituting Equation (16) for Equation (9) yields the market share of firm  $A$ . In the same way, substituting Equation (17) for Equation (10) yields the market share of firm  $B$ :

$$t_A = \frac{(1-\theta^\beta)n_A^\beta - n_B^\beta + 3}{6}, \quad (18)$$

$$t_B = \frac{n_B^\beta - (1-\theta^\beta)n_A^\beta + 3}{6}. \quad (17)$$

Substituting Equation (16) and Equation (18) for Equation (11) yields the profits of firm  $A$ . Similarly, substituting Equation (17) and Equation (19) for Equation (11) yields the profits of firm  $B$ :

$$\Pi_A = \frac{((1-\theta^\beta)n_A^\beta - n_B^\beta + 3)^2}{18} - fn_A - C_A, \quad (20)$$

$$\Pi_B = \frac{(n_B^\beta - (1-\theta^\beta)n_A^\beta + 3)^2}{18} - fn_B. \quad (21)$$

Equation (16) shows that the effects of the varieties of software on the hardware price vary with the degree of  $\beta$  and the degree of compatibility. When  $\beta > 1/3$ , an increase of the varieties of software of firm  $A$  sends down the hardware price under the level at which the degree of compatibility is relevant. When  $\beta < 1/3$ , the degree of compatibility affects the impact of the varieties of software of firm  $A$  on the hardware price. If the degree of compatibility is relatively low, thus  $1-3\beta-\theta^\beta > 0$ , an increase in the varieties of software of firm  $A$  sends up the hardware price. If the degree of compatibility is relatively high, thus  $1-3\beta-\theta^\beta < 0$  an increase in the varieties of software of firm  $A$  sends down the hardware price. An increase in the varieties of software of firm  $B$  decreases the hardware price of firm  $A$ . Equation (17) shows that the effects of the varieties



of software for the hardware price vary with the degree of  $\beta$ . When  $\beta > 1/3$ , an increase in the varieties of software of firm  $B$  sends down the hardware price. When  $\beta < 1/3$ , an increase in the varieties of software of firm  $B$  sends up the hardware price. An increase in the varieties of software of firm  $A$  decreases the hardware price of firm  $B$ . Equation (16) and (17) show that when the software price is high, the hardware price tends to decrease when  $\beta$  is large enough. Otherwise, Equation (17) shows that when the software price is low, the hardware price tends to increase. However, even if  $\beta$  is small enough, Equation (16) shows that firm  $A$  decreases the hardware price in order to prevent consumers from purchasing the hardware of firm  $B$  when the degree of compatibility is relatively large. When the degree of compatibility is relatively small, the value for consumers purchasing technology  $B$  is less likely to increase. In this situation, increasing the varieties of software of firm  $A$  increases the hardware price.

From Equation (18) and (19), we show that an increase in a company's own varieties of software sends up its market share. However, an increase the competitor's varieties of software sends down the market share. Increasing the degree of compatibility sends down the market share of firm  $A$  and sends up that of firm  $B$ . Equation (20) and Equation (21) show that an increase in the varieties

of software of firm  $i$  sends up the profits of firm  $i$ , and an increase in the varieties of software of firm  $j$  sends down the profits of firm  $i$  irrespective of the value of  $\beta$ .

When the condition holds  $|(1-\theta^\beta)n_A^\beta - n_B^\beta| > 3$ , the market share of technology  $i$  is equal to one. When  $t_A=1$ , solving a simultaneous equation of Equation (9), in which  $t_A=1$  is substituted, and Equation (15) yields

$$p_A = (1-\beta-\theta^\beta)n_A^\beta - n_B^\beta - 1, \quad (22)$$

$$p_B = -\beta n_B^\beta. \quad (23)$$

Substituting Equation (22) for Equation (11) yields the profits of firm  $A$ :

$$\Pi_A = (1-\theta^\beta)n_A^\beta - n_B^\beta - 1 - fn_A - C_A. \quad (24)$$

From Equation (22), when either or both  $\theta$  and  $\beta$  are relatively high, the hardware price may be negative. This negative price indicates that a subsidy is given for a consumer by the firm. Substituting Equation (23) for Equation (11) yields the profits of firm  $B$ . The profits of firm  $B$  are negative, indicating the development costs of technology  $B$ . Supposing that  $f$  is fully small, firm  $A$  can earn the positive profit. Thus, when firm  $A$  commits to supplying an extra variety of software, firm  $B$  does not enter the market to prevent making negative profits.

## V. Software choice by firm $B$

In the second stage, firm  $B$  commits to a variety of software and decides to enter the market. We set  $\beta=1/2$  so that we could analyze this model.<sup>6)</sup>

### 1. Monopoly by firm $B$

When firm  $A$  exits the market and firm  $B$  decides to supply software, firm  $B$  becomes a monopolist. When firm  $A$  exits the market, firm  $A$  does not commit to supplying the additional variety of software. Then, firm  $B$  can use only its own software. Rearranging Equation (13) yields the profits of firm  $B$ :

$$\Pi_B = n_B^{1/2} + \alpha - 1 - fn_B. \quad (25)$$

Maximizing Equation (25) yields the optimal varieties of software of firm  $B$ :

$$n_B^m = \frac{1}{4f^2}. \quad (26)$$

Equation (26) shows that an increase in the software development costs decreases the varieties of software. Substituting Equation (26) for Equation (12) yields the price of hardware  $B$ :

$$p_B^m = \frac{1}{4f} + \alpha - 1. \quad (27)$$

Equation (27) shows that an increase in the software development costs decreases the price of software. Substituting

Equation (26) for Equation (25) results in the profits of firm  $B$ :

$$\Pi_B^m = \frac{1}{4f} + \alpha - 1. \quad (28)$$

Equation (28) shows that an increase in the software development costs decreases the profits of firm  $B$ .

### 2. Duopoly

When firm  $A$  accommodates the entry of firm  $B$ , firm  $B$  can choose the varieties of software to maximize the profits given the varieties of software of firm  $A$  and the degree of compatibility. Rearranging Equation (21) yields the profits of firm  $B$ :

$$\Pi_B = \frac{(n_B^{1/2} - (1 - \theta^{1/2})n_A^{1/2} + 3)^2}{18} - fn_B. \quad (29)$$

Maximizing Equation (29) yields the optimal number of varieties of software of firm  $B$ :

$$n_B^a = \left( \frac{3 - (1 - \theta^{1/2})n_A^{1/2}}{18f - 1} \right)^2. \quad (30)$$

Since the second-order condition must hold a negative value,

$$n_A < \frac{9}{(1 - \theta^{1/2})^2}. \quad (31)$$

Substituting Equation (30) for Equation (29) yields the profits of firm  $B$ :

$$\Pi_B^a = \frac{(3 - (1 - \theta^{1/2})n_A^{1/2})^2 f}{18f - 1}. \quad (32)$$

Equation (30) shows that an increase in the varieties of software of firm  $A$  decreases the varieties of software of firm  $B$ . Equation (32) shows that an increase in the varieties of software of firm  $A$  decreases the profits of firm  $B$ . From the denominator of Equation (32),  $f$  must hold at  $f > 1/18 \equiv f_1$  in order for the profits of firm  $B$  to have a positive value. An increase in the varieties of software of firm  $A$  decreases the market share of firm  $B$ .

## VI. Software choice by firm $A$

In this section, firm  $A$  decides whether or not to exit the market. Firm  $A$  commits to additional varieties of software when firm  $A$  stays in the market. If firm  $A$  can earn positive profits, firm  $A$  can choose from three strategies: blockade, deter, and accommodate the entry of firm  $B$ . Otherwise, firm  $A$  exits the market and does not commit to the additional varieties of software.

### 1. Monopoly by firm $A$

When firm  $A$  blockades the entry of firm  $B$ , firm  $A$  is a monopolist. Rearranging Equation (13) yields the monopoly profits of firm  $A$ :

$$\Pi_A = n_A^{1/2} + \alpha - 1 - fn_A - C_A. \quad (33)$$

Maximizing Equation (33) yields the

optimal varieties of software of firm  $A$ :

$$n_A^m = \frac{1}{4f^2}. \quad (34)$$

Comparing Equation (31) with Equation (34), the condition by which firm  $A$  becomes a monopolist is  $f \leq (1 - \theta^{1/2})/6 \equiv f_3$ . Substituting Equation (34) for Equation (12) yields the price of hardware  $A$ :

$$p_A^m = \frac{1}{4f} + \alpha - 1. \quad (35)$$

Substituting Equation (34) for Equation (13) results in the profits of firm  $A$ :

$$\Pi_A^m = \frac{1}{4f} + \alpha - 1 - C_A. \quad (36)$$

Equation (36) shows that an increase in the software development costs decreases the profits of firm  $A$ . Consequently, we have the following proposition:

### PROPOSITION 6.1

If  $f$  is lower than or equal to  $f_1$  or  $f_3$  (whichever is higher), the entry of firm  $B$  is blockaded.

**proof:** When  $f \leq f_1$ , firm  $B$  cannot earn positive profits. When  $f \leq f_3$ , firm  $B$  cannot hold the second-order condition of profit maximization. Thus, firm  $B$  does not enter the market in these conditions and firm  $A$  become a monopolist. Q. E. D.

When  $f$  is small, firm  $A$  can easily monopolize the market. Otherwise, firm  $A$  commits to the appropriate varieties of software to monopolize the market or gives up its monopoly. An increase in the software compatibility decreases  $f_3$ . When  $f_1$  equals  $f_3$ ,  $\theta$  equals  $4/9$ . So, when  $\theta$  is larger than  $4/9$ ,  $f_1$  is larger than  $f_3$ . Therefore, the degree of  $f$  by which firm  $A$  can monopolize decreases with an increase in the degree of compatibility.

### 2. Entry deterrence of firm $B$

If the software development costs are high so that firm  $B$  may decide the entry, firm  $A$  can deter the entry of firm  $B$  by committing to the appropriate varieties of software,

$$n_A^d = \frac{9}{(1-\theta^{1/2})^2}. \quad (37)$$

When Equation (37) is satisfied, the second-order condition for firm  $B$  to enter the market is not satisfied. Therefore, firm  $A$  monopolizes the market. Equation (37) shows that an increase in the degree of compatibility increases the varieties of software. When the degree of compatibility increases, firm  $A$  needs more varieties of software to monopolize the market. Substituting Equation (37) for Equation (12) yields the price of hardware  $A$  :

$$p_A^d = \frac{3}{2(1-\theta^{1/2})} + \alpha - 1. \quad (38)$$

Equation (38) shows that an increase in the degree of compatibility increases the price of hardware of firm  $A$ . Substituting Equation (37) for Equation (13) results in the profits of firm  $A$  :

$$\Pi_A^d = \frac{3}{1-\theta^{1/2}} + \alpha - 1 - \frac{9f}{(1-\theta^{1/2})^2} - C_A. \quad (39)$$

Equation (39) shows that an increase in the software development costs decreases the profits. An increase in the degree of compatibility also decreases profits.

### 3. Entry accommodation of firm $B$

If firm  $A$  cannot blockade or deter the entry of firm  $B$ , firm  $A$  accommodates the entry of firm  $B$ . Substituting Equation (30) for Equation (20) yields the profits of firm  $A$  :

$$\Pi_A = \frac{2(3f(3+(1-\theta^{1/2})n_A^{1/2})-1)^2}{(18f-1)^2} - fn_A - C_A. \quad (40)$$

Maximizing Equation (40) yields the optimal varieties of software of firm  $A$  :

$$n_A^{1/2} = \frac{6(1-\theta^{1/2})(9f-1)}{(18f-1)^2 - 18f(1-\theta^{1/2})^2}. \quad (41)$$

The second-order condition of Equation (40) is  $f > 1/19 \equiv f_2$ . Equation (41) shows that an increase in the degree of compatibility decreases the varieties of software of firm  $A$ .<sup>7)</sup> Substituting Equation (41) for Equation (40) yields the optimal profits of firm  $A$  :

$$\Pi_A^a = \frac{2(9f-1)^2}{(18f-1)^2 - 18f(1-\theta^{1/2})^2} - C_A. \quad (42)$$

Equation (42) shows that an increase in the degree of compatibility decreases the profit. Differentiating Equation (42) with respect to the software development costs,

$$\frac{\partial \Pi_A^a}{\partial f} = \frac{36(9f-1)((18f-1)-(9f+1)(1-\theta^{1/2})^2)}{((18f-1)^2 - 18f(1-\theta^{1/2})^2)^2}. \quad (43)$$

We find that the degree of  $((18f-1)^2 - 18f(1-\theta^{1/2})^2)^2$  does not affect Equation (43). When  $f = 1/9$ , Equation (43) is equal to zero. When  $(18f-1) - (9f+1)(1-\theta^{1/2})^2 = 0$ , we set  $(2-2\theta^{1/2}+\theta)/(9(1+2\theta^{1/2}-\theta)) \equiv f_a$ . When  $1/9 < f_a$ , an increase in the software development costs increases the profits for  $f_a < f$ . When  $f_a \leq 1/9$ , an increase in the software development costs increases the profits for  $1/9 \leq f_a$ .<sup>8)</sup> Thus, firm  $A$  prefers accommodating to deterring the entry of firm  $B$  for software with sufficiently large development costs. An increase in the degree of compatibility decreases the market share of firm  $A$ .

## VII. Equilibrium outcomes

Firm  $A$  chooses its strategies according to the software development cost and the degree of compatibility. They cause four types of equilibrium. We have the following propositions.

### PROPOSITION 7.1

Suppose that  $f_1 \leq f_3$ . When  $f_3 < f < f(\alpha)$ , firm  $A$  deters the entry of firm  $B$ . When  $f(\alpha) < f$ , firm  $A$  accommodates the entry of firm  $B$ .

**proof:** From Proposition 6.1, firm  $B$  enters the market when  $f > f_3$ . Thus, we see that firm  $A$  deters or accommodates the entry of firm  $B$  when  $f > f_3$ . Equation (43) shows that an increase in the software development costs of firm  $A$  decreases the deterrence profits, when the software development costs are sufficiently large. Added to this, an increase of  $\alpha$  translates the deterrence profits to the right. When  $\alpha = 3/2$ , the deterrence profits are at a minimum. We assume that  $\phi$  is the difference of Equation (39) and Equation (42),  $\phi = \Pi_A^d - \Pi_A^a$ . When  $\phi = 0$ , the deterrence profits is indifferent to the duopoly profit. At this time, we assume that the software development cost is  $f(\alpha)$ .

As we show above,  $\Pi_A^a$  increases for  $f_a < f$  when  $1/9 < f_a$ . Substituting  $f_a$  and  $\alpha = 3/2$  for  $\phi$ ,

$$\hat{\phi} = \frac{11 + 63\theta^{1/2} - 46\theta + 30\theta^{3/2} - 11\theta^2 + \theta^{5/2}}{2(1-\theta^{1/2})(1+2\theta^{1/2}-\theta)(\theta-2\theta^{1/2}+5)}. \quad (44)$$

Differentiating Equation (44) with respect to the degree of compatibility, we find that an increase in the degree of compatibility increases  $\hat{\phi}$  for  $0 < \theta < 1$ . Substituting

$\theta = 0$  for Equation (44),  $\hat{\phi} = 11/10$ . Substituting  $\theta = (\sqrt{2}-1)^2/2$ ,  $\hat{\phi} = 3(2\sqrt{2}-1)/2$ . Thus,  $\hat{\phi} > 0$  for  $0 < \theta < (\sqrt{2}-1)^2/2$ . At this time,  $f(\alpha)$  is consistently higher than  $f_a$ .

When  $1/9 > f_a$ ,  $\Pi_A^a$  increases for  $1/9 < f$ . Substituting  $f = 1/9$  and  $\alpha = 3/2$  for Equation (39) and Equation (42),

$$\bar{\phi} = \frac{(4-\theta^{1/2})^2-11}{2(1-\theta^{1/2})^2}. \quad (45)$$

When Equation (45) has a positive value,  $\theta < (4-\sqrt{11})^2$ . When  $f_1 = f_3$ ,  $\theta = 4/9$ . From  $(4-\sqrt{11})^2 > 4/9$ , Equation (45) has a positive value when  $\theta \leq 4/9$ . Thus,  $f(\alpha) > 1/9$  when  $\theta \leq 4/9$ . Consequently, when  $f_3 < f < f(\alpha)$ , firm  $A$  deters the entry of firm  $B$ . When  $f(\alpha) < f$ , firm  $A$  accommodates the entry of firm  $B$ . Q. E. D.

**PROPOSITION 7.2**

Suppose that  $f_3 < f_1$  and  $f_2 < f(\alpha)$ . When  $f_1 < f < f(\alpha)$ , firm  $A$  deters the entry of firm  $B$ . When  $f(\alpha) < f$ , firm  $A$  accommodates the entry of firm  $B$ .

**proof:** From Proposition 6.1, firm  $B$  enters the market when  $f > f_1$ . Thus, we see that firm  $A$  deters or accommodates the entry of firm  $B$  when  $f > f_1$ . From Proposition 7.1,  $f_3 < f_1$  when  $4/9 < \theta$ . Added to this, when  $4/9 < \theta < (4-\sqrt{11})^2$ , Equation (45) has a positive value. Thus,  $f(\alpha) > f_2$  and firm  $A$  deters the entry of firm  $B$  when  $f(\alpha) > f$ . Here,  $f_1 < f_2$

always holds because of  $f_1 \equiv 1/18$  and  $f_2 \equiv 1/9$ . Therefore, when  $f_1 < f < f(\alpha)$ , firm  $A$  deters the entry of firm  $B$ . When  $f(\alpha) < f$ , firm  $A$  accommodates the entry of firm  $B$ . Q. E. D.

From proposition 7.1 and 7.2, the software development costs to deter the entry of firm  $B$  are interpreted as the costs that firm  $A$  can earn the larger profits than when firm  $A$  accommodates the entry of firm  $B$  even if firm  $A$  commits the large varieties of software. The degree of compatibility of proposition 7.1 is smaller than the degree of compatibility of proposition 7.2. Therefore, the software development costs to deter the entry of firm  $B$  in proposition 7.2 are smaller than that in proposition 7.1. Because firm  $A$  must supply the larger varieties of software than ever before to deter the entry of firm  $B$ .

**PROPOSITION 7.3**

Suppose that  $f_3 < f_1 < f_d(0) \leq f_2$ . When  $f_1 < f < f_d(0)$ , firm  $A$  deters the entry of firm  $B$ . When  $f_d(0) \leq f \leq f_2$ , firm  $B$  monopolizes the market. When  $f_2 < f$ , firm  $A$  accommodates the entry of firm  $B$ .

**proof:** When  $\Pi_A^d = 0$ , we set the software development costs at  $f_d(0)$ . The second-order condition for firm  $A$  accommodating the entry of firm  $B$  is  $f > 1/9$ . Thus, firm  $A$  exits the market and firm  $B$  becomes a

monopolist when  $f = f_d(0) = 1/9 = f_2$ . By the same token, firm  $B$  monopolizes the market when  $f_d(0) \leq f \leq f_2$ . When  $f < f_d(0)$ ,  $\Pi_A^d$  has a positive value so that  $\Pi_A^d$  decreases with an increase in the software development costs. Consequently, firm  $A$  can deter the entry of firm  $B$  when  $f_1 < f < f_d(0)$ . Firm  $A$  accommodates the entry of firm  $B$  when  $f_2 < f$ . Q. E. D.

When the software development costs are small, if firm  $A$  accommodates the entry of firm  $B$ , firm  $A$  may not earn the positive profits. Then, firm  $A$  increases the varieties of software to deter the entry of firm  $B$  or exits the market. When firm  $A$  decides the exit, the software development costs are relatively large. Because increasing the varieties of software brings the negative profits to firm  $A$ . Therefore, firm  $B$  can monopolize the market.

**PROPOSITION 7.4**

Suppose that  $f_3 < f_d(0) \leq f_1$ . When  $f_1 < f \leq f_2$ , firm  $B$  becomes a monopolist. When  $f_2 < f$ , firm  $A$  accommodates the entry of firm  $B$ .

**proof:** From Proposition 6.1, firm  $B$  can enter the market when  $f > f_1$  and firm  $A$  monopolizes the market when  $f \leq f_1$ . From Proposition 7.3, firm  $A$  exits the market when  $f \leq f_2$ . Thus, firm  $B$  can monopolize the market when  $f_1 < f \leq f_2$ . Firm  $A$  accommodates the entry of firm

$B$  when  $f_2 < f$ . Q. E. D.

From these propositions, when the software development costs are moderate, the following things can be said. Firm  $A$  can deter the entry of firm  $B$  when the degree of compatibility is small. The small degree of compatibility means that firm  $B$  cannot imitate firm  $A$ 's technology because firm  $A$  has the high level of technology and firm  $B$  has the low level of that. Then, firm  $A$  has an advantage because firm  $A$  can decide the varieties of software earlier. Therefore, ensuring the installed base is important for firm  $A$  when the degree of compatibility is small. However, Firm  $B$  can monopolize the market and firm  $A$  exits the market when the degree of compatibility is large enough. The large degree of compatibility means that firm  $B$  can easily imitate firm  $A$ 's technology because firm  $A$  has the low level of technology and firm  $B$  has the high level of that. Then, it does not become an advantage that firm  $A$  decides the varieties of software earlier. Because the varieties of software of firm  $A$  drastically increase the value of system of firm  $B$  in the large degree of compatibility. Therefore, firm  $A$  cannot deter the entry of firm  $B$  and firm  $A$  decides to exits the market when the degree of compatibility is large enough. When the degree of compatibility is intermediate, firm  $A$  can deter the entry of firm  $B$  or firm  $B$  can monopolize the

market. The greater the value of  $\alpha$ , the more the degree of software development costs cause firm  $A$  to deter the entry of firm  $B$ . We show that firm  $A$  and  $B$  coexist without any degree of compatibility under sufficiently large software development costs. Then, firm  $A$  cannot commit the large varieties of software to monopolize the market because of the large software development costs. Therefore, firm  $A$  accommodates the entry of firm  $B$ . When the degree of software development costs are sufficiently small, firm  $A$  monopolizes the market.

Figure 1 illustrates the equilibrium areas.

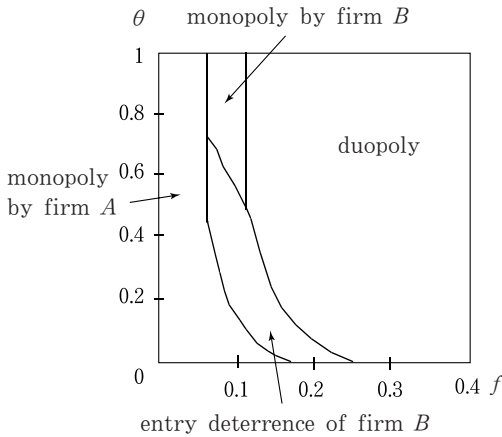


Figure 1: Equilibrium for parameters  $0 \leq f \leq 2/5, \alpha = 3/2, C_A = 0$

### VIII. Welfare analysis

In this section, we investigate the welfare. First, we focus on the case in which firm  $i$  monopolizes the market.<sup>9)</sup> Consumers only purchase technology  $i$ .

Substituting Equation (34) and Equation (35) for Equation (7) and integrating it yield the consumer surplus when firm  $i$  monopolizes:

$$CS_i^m = y + \frac{1}{2}. \quad (46)$$

The total surplus is measured by adding the consumer surplus and the profits of firms. Adding Equation (46) and Equation (28) yields the total surplus:

$$TS_i^m = \frac{1}{4f} + y + \alpha - \frac{1}{2} - C_i. \quad (47)$$

By the same token, we find the consumer and total surplus when firm  $B$  monopolizes the market.

When firm  $A$  deters the entry of firm  $B$ , consumers can only purchase technology  $A$ . Substituting Equation (37) and Equation (38) for Equation (7) and integrating it yield the consumer surplus when firm  $B$  is deterred:

$$CS^d = y + \frac{1}{2}. \quad (48)$$

Adding Equation (48) and Equation (39) yields the total surplus when firm  $B$  is deterred:

$$TS^d = \frac{3(1-\theta^{1/2})-9f}{(1-\theta^{1/2})^2} + y + \alpha - \frac{1}{2} - C_A. \quad (49)$$

When firm  $A$  accommodates the entry of firm  $B$ , consumers can purchase either one of the two technologies. The



consumer surplus of the duopoly is measured by adding the two consumer surpluses. Substituting Equation (41), Equation (30), Equation (17) and Equation (16) for Equation (7) and Equation (8) yields the consumer surplus:

$$\begin{aligned} CS^a &= CS_A^a + CS_B^a \\ &= \frac{6(18f-1)(9f-1)^2(3-2\theta^{1/2}-18f)}{((18f-1)^2-18f(1-\theta^{1/2})^2)^2} \\ &\quad + \frac{2(\alpha+y)(18f-1)(9f-1)}{(18f-1)^2-18f(1-\theta^{1/2})^2}. \end{aligned} \quad (50)$$

Substituting Equation (41) for Equation (32) and adding Equation (50), Equation (42) and Equation (32) yield the total surplus when firm  $A$  accommodates firm  $B$ :

$$\begin{aligned} TS^a &= CS^a + \Pi_A + \Pi_B \\ &= \frac{16-531f-36\theta^2(18f-1)f+5944f^2-29160f^3+52488f^4-144\theta^{3/2}f(18f-1)}{((18f-1)^2-18f(1-\theta^{1/2})^2)^2} \\ &\quad + \frac{36f\theta(8-162f+405f^2)-12\theta^{1/2}(1-12f-135f^2+972f^3)}{(18f-1)^2-18f(1-\theta^{1/2})^2} \\ &\quad + \frac{2(\alpha+y)(18f-1)(9f-1)}{(18f-1)^2-18f(1-\theta^{1/2})^2} - C_A. \end{aligned} \quad (51)$$

### PROPOSITION 8.1

When firm  $A$  deters the entry of firm  $B$ , the total surplus of deterrence is lower than that of a firm  $B$  monopoly.

**proof:** Subtracting Equation (49) from Equation (47),

$$TS_B^m - TS^d = \frac{((1-\theta^{1/2})-6f)^2}{4f(1-\theta^{1/2})^2} + C_A. \quad (52)$$

The first term of right-hand side has a positive value because the software development costs and the degree of

compatibility are real numbers. Added to this, we assume that  $C_A > C_B$ . Thus, when  $f \leq 1/9$ ,  $TS_B^m > TS^d$ . Q. E. D.

### PROPOSITION 8.2

When  $(3-2\sqrt{2})/2 < \theta < \hat{\theta}$  and  $1/9 < f < f(\alpha)$  under an extremely high income,  $CS^a < CS^d$  and  $TS^a < TS^d$

**proof:** Subtracting Equation (48) from Equation (50),

$$\begin{aligned} CS^a - CS^d &= \frac{(18f(1-\theta^{1/2})^2-(18f-1)y}{(18f-1)^2-18f(1-\theta^{1/2})^2} + \frac{6(9f-1)(18f-1)^2}{2((18f-1)^2-18f(1-\theta^{1/2})^2)^2} \\ &\quad + \frac{24(18f-1)(18f-4)(1-\theta^{1/2})^2-18(f-1)^4-324f^2(1-\theta^{1/2})^4}{2((18f-1)^2-18f(1-\theta^{1/2})^2)^2}. \end{aligned} \quad (53)$$

When the denominator of the first term of the right-hand side of Equation (53) is equal to zero, the denominator of the second term of the right-hand side of Equation (53) is also equal to zero. At this time, moreover, the denominator of the third term of the right-hand side of Equation (53) is equal to zero. If  $y$  has a high positive value, the value of Equation (53) independently changes the second and third terms of its right-hand side. We assume that the numerator of the first term of the right-hand side of Equation (53) is equal to  $\phi$ ,  $\phi = 18f(1-\theta^{1/2})^2 - 18f + 1$ . Differentiating  $\phi$  with respect to  $\theta$  results in  $\partial\phi/\partial\theta < 0$ . Thus,  $\phi$  constantly decreases in reaction to an increase in the degree of compatibility. We assume

that the denominator of the first term of the right-hand side of Equation (53) is equal to  $\mu$ ,  $\mu = (18f-1)^2 - 18f(1-\theta^{1/2})^2$ . Differentiating  $\mu$  with respect to  $\theta$  results in  $\partial\mu/\partial\theta > 0$ . Thus,  $\mu$  constantly increases in reaction to an increase in the degree of compatibility. Changing the first term of the right-hand side of Equation (53), we can gain  $(2t_A-1)y$ .  $t_A$  must hold  $t_A < 1$  to have an interior solution. Thus,  $2t_A-1 < 1$ . Assuming that  $\mu$  has a positive value, we find  $\mu > \phi$ . Assuming that  $\phi = 0$  and  $\mu = 0$  and solving, we find  $(f, \theta) = (1/18, 1)$ ,  $(1/9, (3-2\sqrt{2})/2)$  for  $0 < \theta < 1$ . Substituting  $\theta = (3-2\sqrt{2})/2$  for  $\mu$ , we can gain the condition of software development costs,  $f > 1/9$ , to meet  $\mu > 0$ .<sup>10)</sup> Substituting  $f = 1/9$  for  $\mu$ , we can gain the condition of  $\theta$ ,  $(3-2\sqrt{2})/2 < \theta < 1$ , to meet  $\mu > 0$ . Substituting  $\theta = (3-2\sqrt{2})/2$  for  $\phi$  so that  $f > 1/9$ , we find that  $\phi < 0$ . Here, we establish that  $\hat{\theta}$  is a value of  $\theta$  when  $f_d(0) = 1/9$ .  $\phi/\mu < 0$  holds when  $(3-2\sqrt{2})/2 < \theta < \hat{\theta}$  and  $f > 1/9$ . Thus,  $CS^a < CS^d$  holds when  $y$  is a high positive value,  $(3-2\sqrt{2})/2 < \theta < \hat{\theta}$  and  $f > 1/9$ . By the same token,  $TS^a < TS^d$  holds when  $(3-2\sqrt{2})/2 < \theta < \hat{\theta}$ ,  $f > 1/9$  and  $y$  is a high positive value. Q. E. D.

Proposition 8.1 shows that deterring the entry of firm  $B$  depreciates the total surplus. A policy decision maker should prevent firm  $A$  from deterring the entry of firm  $B$  in this situation. However, both consumer surpluses are the same

value. When a policy decision maker focuses on maintaining the consumer surpluses, this situation may not become a problem. Proposition 8.2 shows that deterring the entry of firm  $B$  increases the total surplus and the consumer surplus when firm  $A$  accommodates the entry of firm  $B$  and  $(3-2\sqrt{2})/2 < \theta < \hat{\theta}$ . At this time, the market share of firm  $A$  is lower than half. The number of varieties of software of firm  $A$  is low when firm  $A$  accommodates the entry of firm  $B$ . Therefore, supplying additional varieties of software to deter the entry of firm  $B$  increases the consumer and the total surplus. A policy decision maker must observe the degree of compatibility and software development costs not to choose the wrong policy in this situation.

## IX. Conclusion

In this paper, we have investigated the strategies of two firms that integrate the supply of software with that of hardware when the software of the incumbent firm are partially compatible with the entrant technology. In our model, the software has both direct network effects provided by using compatible software and indirect network effects provided by the varieties of software. Our model structure is the same as that of Church and Gandal (1996), who showed that the varieties of software

became the installed base for the hardware operating them. The incumbent firm tended to overinvest to create the installed base. We extend their model by adding a degree of compatibility.

We have shown that the strategies of the two firms differ according to the degree of compatibility and the software development costs. The degree of compatibility has the potential effect of undermining the installed base that the incumbent firm created. When the degree of compatibility is relatively low and the software development costs are moderate, the incumbent firm deters the competitor's entry by overinvesting. Thus, the incumbent firm creates an installed base by overinvesting because the effects of compatibility are weak. On the other hand, when the degree of compatibility is extremely high and the software development costs are moderate, the incumbent firm does not deter the entry or simply exits the market. Consequently, the first-mover advantage of firm  $A$  disappears.

Analyzing the welfare, we have shown that deterrence does not always decrease the welfare. Deterring the entry of firm  $B$  increases the total surplus and the consumer surplus, when firm  $A$  accommodates the entry of firm  $B$  with a certain degree of compatibility. Thus, supplying additional varieties of software to deter the entry of firm  $B$  increases the consumer surplus and the total surplus.

In our model, we assumed that the degree of compatibility was exogenously given. We can relax this restriction. Thus, firm  $B$  can change the degree of compatibility to maximize its profits, after firm  $A$  accommodates the entry of firm  $B$ . Differentiating Equation (29) with respect to the degree of compatibility yields the first-order condition. Substituting it for Equation (30),  $36f(9f - 1)n_B = 0$ . The optimal varieties of software are equal to zero because the software development costs are given. The optimal profits of firm  $B$  are also equal to zero. Therefore, firm  $B$  cannot obtain the market share and firm  $A$  monopolizes the market.

We assumed that the compatibility was one-way partial compatibility. However, some software practically has two-way compatibility. We also investigated the situation when firm  $A$  also has partial compatibility for the software of firm  $B$  by supposing that the compatibility of firm  $A$  is  $\theta_A$  and similarly implementing the assumptions of compatibility of firm  $B$ . Solving this, we found that the equilibrium features when the software is two-way compatible are generally the same as the equilibrium features when the software is one-way compatible in  $\theta_A < \theta_B$ . The point to note is that  $\theta_A$  is included in  $f_1$  and  $f_2$ . Then,  $f_1$  and  $f_2$  are reduced by increasing  $\theta_A$ . Reducing  $f_1$  shows that firm  $B$  can enter the market at a lower cost than before. Thus, it is

difficult for firm  $A$  to monopolize the market when the degree of compatibility of firm  $A$  is large. Reducing  $f_2$  shows that firm  $A$  can enter the market at a lower cost than before. It is difficult for firm  $B$  to monopolize the market when the degree of compatibility of firm  $A$  is large. If  $\theta_B \leq \theta_A$  holds, the entrant may not monopolize the market or the incumbent may not deter the entrant when the both degree of compatibility are sufficiently large. Then, the incumbent monopolizes the market or accommodates the entry because the compatibility cancels out the installed-base and the price competition is left.

As other expansion of this model, we assume that the Stackelberg competition occurs in the hardware price competition stage. Then, the incumbent becomes a leader and the entrant becomes a follower. Solving this model, we find that the hardware prices of both firms are higher than under the Bertrand competition, and the market share of the entrant is larger than that of the incumbent. Because the incumbent puts the price higher than the entrant in order to get additional profits. However, the incumbent suppresses the market share. Therefore, the incumbent is hard to monopolize the market, but the entrant is easy to enter the market and to monopolize it for lower costs and compatibility.

In this paper, we did not discuss the asymmetrical software development costs and the costs of realizing compatibility. We need to consider the case in which the varieties of software of the incumbent depend on the varieties of software of the entrant. In addition to this, we did not discuss the equilibrium when three or more firms enter the market. These topics require further discussion.

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#### Notes

- 1) Network externalities have an influence on consumers without markets, but network effects include those with and without the transmission of markets.
- 2) See also Church and Gandal (1992, 1993) on indirect network effects.
- 3) We assume that the marginal consumer will always prefer purchasing a system to purchasing outside goods. Substituting Equation (16) and Equation (18) for Equation (7) yields the condition  $(1 + \theta_j^\beta) n_i^\beta + n_j^\beta - 3 + 2\alpha > 0$ . The condition of  $\alpha$  is  $\alpha \geq 3/2$ .
- 4) we assume that software development costs are sunk costs.
- 5) If firm  $i$  is not a monopolist, the market share of firm  $i$  is less than unity. Thus, from Equation (18),  $|(1 - \theta^\beta) n_A^\beta - n_B^\beta| \leq 3$ .
- 6) From Equation (13), (20) and (21), the profits of firm are affected by increasing or decreasing

the varieties of software regardless of the degree of  $\beta$ . Therefore, we can derive general ideas using a fixed  $\beta$ .

- 7) We assume that  $(18f-1)^2-18f(1-\theta^{1/2})^2 > 0$  and  $f$  are real numbers.
- 8) Differentiating  $f_a$  with respect to  $\theta$  results in  $\partial f_a / \partial \theta < 0$  for  $0 < \theta < 1$ . When  $f_a = 1/9$ ,  $\theta = (\sqrt{2}-1)^2/2$  for  $0 < \theta < 1$ . Thus, When  $1/9 < f_a$ ,  $\theta < (\sqrt{2}-1)^2/2$ . When  $f_a > 1/9$ ,  $\theta > (\sqrt{2}-1)^2/2$ .
- 9) The monopolistic hardware price of firm  $A$  is equal to that of firm  $B$ . In the same way, the monopolistic varieties of software of firm  $A$  are equal to those of firm  $B$ .
- 10) firm  $B$  must holds  $f > 1/18$  to enter the market.

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(Graduate Student, Graduate School of Economics, Nagoya University)