

## Integration between Hardware and Software Producers in the Presence of Indirect Network Externalities

by  
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*Abstract:* This paper aims to analyze the effects of the integration between hardware and software producers in the presence of indirect network externalities. Even without this integration, a hardware producer can subsidize independent software producers for the provision of more software products. The integration, however, may facilitate the integrated firm to coordinate for the development of software products, giving the integrated firm a first-mover advantage in the subsidization for software development. To highlight this first-mover advantage of the integrated firm, we posit a situation in which there exist an integrated (incumbent) hardware/software firm and an un-integrated (entering) hardware firm. With this first-mover advantage, the incumbent can choose either to accommodate or to deter the entry by enhancing the applications barrier to entry. Extending the model of Katz and Shapiro (1985), we will show that the accommodation equilibrium is always socially more beneficial (in terms of consumer surplus) than the duopoly equilibrium with the breakup of the incumbent. Furthermore, the deterrence equilibrium can be socially more beneficial as well if the entrant's fixed start-up cost is sufficiently low.

### *1. Introduction*

This paper aims to analyze the effects of the integration between hardware and software producers in the presence of indirect network externalities. The indirect network externality is typically caused by a positive feedback effect between a

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hardware product and available software products.<sup>1</sup> The bundle of a PC (such as MS-Windows-equipped PC or Macintosh) and various applications software programs is an example of this traditional hardware/software paradigm of the indirect network externality: an increase in demands for MS-Windows-equipped PCs induces independent software vendors to develop more applications software products available for MS-Windows-equipped PCs, which in return raise a consumer's benefit from using an MS-Windows-equipped PC and thus its demands.<sup>2</sup> Hence, in the presence of indirect network externalities, a consumer purchasing a hardware product raises the value of this hardware product for the other consumers *indirectly* since an increase in demands for the hardware product typically induces a greater variety of available software products. As a result, the overall economic value to the society exceeds the economic benefit enjoyed by a consumer from purchasing a hardware product. In this sense, the indirect network externality is understood as a positive consumption externality.<sup>3</sup>

The integration between hardware and software producers in the presence of indirect network externalities has caught more attentions due to the recent historical antitrust lawsuit against Microsoft. In Findings of Fact released on November 5 in 1999, Judge Thomas Penfield Jackson concluded that Microsoft possessed monopoly power in the PC operating systems market.<sup>4</sup> Judge Jackson sided with the plaintiffs, the Department of Justice and the 19 states, in that (i) Microsoft maintained a dominant and persistent market share, and the applications barrier to entry protected its dominant market share;<sup>5</sup> and (ii) Microsoft used its monopoly in operating systems to stifle competition in the applications programs and the Web browser markets. In the verdict released on April 3, 2000,

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<sup>1</sup>In the presence of *direct network externalities*, the consumer's utility increases directly with the number of the other users. The examples of direct network externalities include a communications network, such as the network of e-mail users, the network of fax machines, or the network of people who exchange MS Words files.

<sup>2</sup>There are many examples of hardware/software systems: a VCR and prerecorded videocassette tapes; a DVD player and video disks; a digital TV and TV programs; or a home video game system and video game cartridges.

<sup>3</sup>Some researchers consider indirect network externalities as positive production externalities (see, for examples, Liebowitz and Margolis, 1995). In this case, an increase in demands for a hardware product causes a decline in the prices of software products and thus input costs of that hardware product.

<sup>4</sup>Microsoft occupies more than 95 percent of the worldwide market for the Intel-compatible PC operating systems market and well above 80 percent even if the Macintosh operating systems were included in the market.

<sup>5</sup>The huge installed base of MS-Windows-equipped PCs can constitute an applications barrier to entry via the positive feedback effects of indirect network externalities.

Judge Jackson ruled: “Microsoft maintained its monopoly power by anticompetitive means and attempted to monopolize the Web browser market, both in violation of §2. Microsoft also violated §1 of the Sherman Act by unlawfully tying its Web browser to its operating system”. Accepting the plaintiffs’ remedy proposal in its entirety, on June 7, 2000, Judge Jackson ordered not only several conduct restrictions<sup>6</sup> but also the breakup of Microsoft into two separate companies, one for MS Windows operating system and the other for its other software programs and Internet businesses. A federal appeals court, however, voided this breakup order on June 28, 2001. The plaintiffs and Microsoft could appeal to the Supreme Court, proceed to a new trial before a different district judge, or reopen settlement negotiations.

Although the Judge Jackson’s breakup order is not likely to be reinstated, it leaves us with a challenging question: what (welfare) consequences might the breakup of Microsoft have led to in the PC market?<sup>7</sup> To explore this question, this paper studies the incentives and the consequences of the integration between hardware and software producers in the presence of indirect network externalities. Indeed, the integration between hardware and software producers is also an important issue in many other industries such as the Digital TV industry and the home video game systems industry. Before we proceed, note that in the case of Microsoft, there are three types of products involved: computer hardware body, operating system, and applications software. In the context of the traditional hardware/software paradigm of the indirect network externality, the bundle of the computer hardware body and an operating system can be considered a hardware product while applications software programs (such as word processors and spread sheets) running on the operating system are considered software products. Hence, in the paper, the bundle of a computer hardware body and the MS Windows is called an MS-Windows-equipped PC while the bundle of a computer hardware body and the Macintosh operating system is called a Macintosh. Note also that in the case of the MS-Windows-equipped PC, the operating system producer (Microsoft) and the computer body manufacturer (such as Dell) are not *vertically* integrated, while in the case of the Macintosh, they are vertically integrated. However, as discussed in the economics literature, the upstream firm can control downstream firms to behave like a vertically

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<sup>6</sup>The conduct restrictions would not only prevent tying MS Internet Explorer (a Web browser) to MS Windows but also allow computer manufacturers to offer customized versions of MS Windows and software features. Refer to “Microsoft Breakup is Ordered for Antitrust Law Violations” in *New York Times*, June 8, 2000.

<sup>7</sup>Although the Microsoft case motivated this paper, the paper is not attempting to model or address all the issues involved in the Microsoft case such as bundling of MS Windows and MS Internet Explorer. For a comprehensive review of the Microsoft case, refer to Economides (2000).

integrated firm by contract. Hence, we do not explicitly consider the vertical control issues between the operating system producer (upstream firm) and the computer body manufacturers (downstream firms), treating the Microsoft as a vertically integrated firm, i.e., the MS-Windows-equipped PC producer. Recall that our main focus is on the integration between a hardware producer (e.g., MS-Windows-equipped PC producer) and software producers (e.g., producers of MS Word, MS Excel, etc.).

As in many markets with complementary products or externality-generating products, the hardware producer may have an incentive to internalize the indirect network externality. The integration between hardware and software producers will internalize this externality since the integrated firm can support a greater variety of software products than supplied by the (monopolistically competitive) market without integration.<sup>8</sup> Even without the integration, however, a hardware producer may be able to subsidize (by contract or other means) independent software producers for the provision of more software products.<sup>9</sup> Yet, the integrated firm may have an advantage since the integration may further facilitate the hardware producer to coordinate for the development of available software products. Hence, in the paper, the integration will be considered to give the hardware producer a *first-mover advantage* in subsidizing for the development of available software.

To analyze the welfare consequences of the integration between hardware and software producers, we will begin with a (monopolist) hardware producer's optimal subsidization behavior. In principle, the hardware producer will subsidize software producers as long as his/her marginal benefit from the subsidization is greater than or equal to the marginal cost of the subsidization.<sup>10</sup> Based on the model for the mechanism of the indirect network externality in Park (2002), we will derive both a hardware producer's marginal benefit from subsidization and a subsidy function necessary to compensate for software producers' losses from producing an excessive variety of software products. In the presence of

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<sup>8</sup>Network externalities are also partly internalized by pricing (or quantity-setting) behavior since the firm takes into account that a lower price attracts more consumers which in return induce more demands through network externalities. Refer to Park (forthcoming).

<sup>9</sup>Microsoft has also engaged in explicit subsidization to independent software vendors for the development of applications software for MS Windows. One of Microsoft's rebuttals to the applications barrier to entry at the trial was that the huge number of applications software programs for MS Windows was partly due to the effort Microsoft had made. R.L. Schmalensee testified in favor of Microsoft: "Microsoft spent \$630 million in fiscal year 1998 to help software developers write applications for MS Windows family of operating system products".

<sup>10</sup>Hence, in the presence of indirect network externalities, the monopolist does not need to invite entries as discussed in Economides (1996).

indirect network externalities, an increased variety of available software products induced by strategic subsidization will enhance the sales of hardware products and consumer surplus. However, a hardware producer's marginal benefit from more available software products does not count for an increased consumer surplus and thus is smaller than the social marginal benefit. Hence the hardware producer's subsidization will not be sufficient to achieve an efficient outcome.

Note that Kende (1998) discussed conditions for a monopolist hardware producer (or the system manufacturer in his term) to choose an open system in which the hardware producer allows (by opening the specifications of the hardware product) other software firms to produce the available software products (or the secondary goods in his term). Kende (1998) showed that due to indirect network externalities, the increased profits in the hardware product market induced by a greater variety supplied under the open system can dominate the foregone monopoly profits in available software products markets. In this paper, we go further to show that the hardware producer even has an incentive to subsidize software producers to internalize this indirect network externality under the open system (or in the existence of independent software producers in our term).

The integration between hardware and software producers further gives the integrated firm a first-mover advantage in the subsidization for software development. To highlight this first-mover advantage of the integrated firm, we posit a situation in which there exist an integrated (incumbent) hardware/software firm and an un-integrated (entering) hardware firm.<sup>11</sup> Both firms can subsidize independent software producers for the provision of more software products. With the first-mover advantage, however, the integrated firm can choose either to accommodate or to deter the entry by enhancing applications barrier to entry. The welfare consequences of this first-mover advantage are striking. Extending the model of Katz and Shapiro (1985), we will show that the accommodation equilibrium is always socially more beneficial (in terms of consumer surplus) than the duopoly equilibrium with the breakup of the incumbent. Furthermore, the deterrence equilibrium can be socially more beneficial as well if the entrant's fixed start-up cost is sufficiently low. In other words, the breakup is more likely to induce entry, but consumer surplus may be higher even when the integrated incumbent deters entry.

The paper is organized as follows. Section 2 posits the model and obtains a hardware producer's marginal benefit from subsidization and a subsidy function

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<sup>11</sup>In the paper, we do not attempt to explain why the entering firm is not integrated although there could be several economic and financial reasons such as huge start-up costs. Church and Gandal (1992) studied the issue of an endogenous integration in the presence of indirect network externalities when two symmetric hardware producers compete in prices.

necessary to compensate for software producers' losses from producing an excessive variety of software products. Section 3 discusses welfare consequences of this strategic subsidization. Section 4 shows that the first-mover advantage in strategic subsidization can constitute a barrier to entry but may be better for consumers if the entrant's fixed start-up cost is sufficiently low. Section 5 concludes the paper. The appendix discusses how our conclusions will be affected in a pricing game with differentiated hardware products.

## *2. The model*

### *2.1 Four-stage framework*

In the paper, we posit a four-stage framework. In the first stage, an integrated hardware/software firm, say firm 1, decides whether and how much it will pre-commit to subsidize for the provision of a variety of software products (greater than supplied without subsidization). The integrated firm commits to this subsidization by supporting for the development costs of available software. In the second stage, an un-integrated (entering) hardware firm, say firm 2, will decide whether to enter or not. In the third stage, if there is an entry, firm 2 can subsidize for the provision of its available software products as well, and firm 1 and firm 2 compete in quantity for any fixed set of committed subsidies. If there is no entry, firm 1 behaves as a monopolist. Each consumer purchases at most one hardware product. In the fourth stage, a variety and quantities of available software products are determined in a monopolistically competitive market with free entry.

We adopt the concept of a rational expectations equilibrium in a sense that consumer expectations for the provision of available software are consistent with both an equilibrium of the hardware products market and an equilibrium of the software products market. Hence, without any subsidization, consumer expectations for the provision of available software will be equal to an equilibrium variety supported by the users of a hardware product. Otherwise, these expectations coincide with hardware producers' committed subsidization. It will be shown that a hardware producer cannot credibly commit to the provision of a variety less than demanded by the users of the hardware product.

### *2.2 Network benefit function and subsidy function*

We begin by specifying a consumer's utility function for the bundle of a hardware product and available software in order to reflect the indirect network externality as a positive consumption externality. The user of a hardware product

will purchase available software products for a combined service. The utility level derived from this combined service depends on the consumer's stand-alone benefit of a hardware product and the variety and the quantity of available software products. Following Park (2002), we assume that consumer  $i$ 's utility level for a bundle of hardware product  $j$  and its available software, say  $U_{ij}$ , is additively separable in: (i) consumer  $i$ 's stand-alone benefit of hardware product  $j$ , say  $V_{ij}$ ,<sup>12</sup> and (ii) a (special form of the) two-sector utility function of the variety and the quantity of available software products and the outside alternative as in Dixit and Stiglitz (1977). Note that the outside alternative, say  $q_{i0}$ , is a composite good other than the products under consideration. In what follows, let  $z_{ik[j]}$  denote the quantity consumed by consumer  $i$  of software product  $k$  available for hardware product  $j$ , and  $K_j$  denote the variety (or the number) of software products available for hardware product  $j$ . For notational simplicity, we let  $z_{ik}$  abbreviate  $z_{ik[j]}$ .

*Assumption 1.* The expected utility level of consumer  $i$  for a bundle of hardware product  $j$  and its available software in the third stage is given by the scalar value:

$$U_{ij} = V_{ij} + E\left[\left(\sum_{k=1}^{K_j} z_{ik}^{1/\beta}\right)^{\beta/(2\beta-1)} + q_{i0}\right],$$

where  $\beta > 1$  and  $E[\cdot]$  is a rational expectation operator conditioned on information available in the third stage, such as committed subsidies and expected sales of hardware products.

The utility function specified in Assumption 1 reflects the indirect network externality as a positive consumption externality in a sense that the consumer prefers a greater variety of available software, and more users of a hardware product induce a greater variety of available software. Refer to Park (2002) for detailed discussions.

Due to the rational expectations assumption, we will solve this four-stage model backward from the fourth stage. In the fourth stage, consumer  $i$  who purchased hardware product  $j$  in the third stage splits the remainder of his/her income between available software products,  $\{z_{ik}\}$ , and the outside alternative,  $q_{i0}$ , to maximize:

$$(1) \quad \left(\sum_{k=1}^{K_j} z_{ik}^{1/\beta}\right)^{\beta/(2\beta-1)} + q_{i0} \quad \text{subject to} \quad q_{i0} + \sum_{k=1}^{K_j} \rho_k z_{ik} = y_i - p_j,$$

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<sup>12</sup> $V_{ij}$  may be treated as a function of the attributes of product  $j$  and consumer  $i$ 's idiosyncratic taste for product  $j$  as in Park (forthcoming) in the case of differentiated products.

where  $\rho_k$  denotes the price of software product  $k$ ,  $y_i$  is consumer  $i$ 's income, and  $p_j$  denotes the price of hardware product  $j$ . Each software maker is assumed to produce a differentiated software product with the same marginal cost, say  $s$ , and the same fixed development cost, say  $F$ .

Following a two-stage budgeting procedure as detailed in Park (2002), we can derive a consumer's demand function for an available software product as follows:

$$z_{ik} = g^{-1}(P_j)(P_j / \rho_k)^{\beta/(\beta-1)}, \text{ where } P_j = (\sum_{k=1}^{K_j} \rho_k^{-1/(\beta-1)})^{-(\beta-1)},$$

and  $g^{-1}$  is the inverse of the derivative of  $f(Z) = Z^{1/(2\beta-1)}$ . In the literature,  $P_j$  is called the price index. A change in  $\rho_k$  alone affects  $z_{ik}$  directly, and also through  $P_j$ . If we assume that  $K_j$  is reasonably large and accordingly neglect the effect of each  $\rho_k$  on  $P_j$  as in Dixit and Stiglitz (1977),<sup>13</sup> then the price elasticity of demand for a software product will be:  $-(\partial z_{ik} / \partial \rho_k) / (z_{ik} / \rho_k) = \beta / (\beta - 1)$ .<sup>14</sup> Hence, we find the equilibrium price of each software product equal to  $\rho = \beta s$  and the equilibrium sales of each software product equal to:

$$(2) \quad z_{ik} = \{(2\beta - 1)\beta s\}^{-(2\beta-1)/2(\beta-1)} K_j^{-1/2}.$$

In order to provide an excessive variety of software, a hardware producer must commit to compensate for software producers' losses from producing more than an equilibrium variety without any subsidization. In what follows, it will be clear that this commitment is equivalent to a hardware producer's guarantee for the provision of a certain level of demands to software producers by purchasing over-supplies of their software products. Let  $B_j$  denote a committed network size of hardware product  $j$  for a certain level of demands for software products, and  $q_j$  denote the actual network size (i.e., the number of users) of hardware product  $j$ . Then with a committed network size  $B_j$ , a variety of available software,  $K_j$ , is endogenously determined by the zero-profit condition imposed by free entry. The zero-profit condition implies:  $(\rho - s)z_k - F = 0$ , where  $z_k = \sum_{i=1}^{B_j} z_{ik}$ . Hence the variety  $K_j$  is given by:

$$(3) \quad K_j = B_j^2 \left( \frac{s(\beta-1)}{F} \right)^2 \{(2\beta-1)\beta s\}^{-(2\beta-1)/(\beta-1)}.$$

<sup>13</sup>There are 70,000 or so applications software programs that now run on MS Windows (see "Microsoft and the future," *The Economist*, November 13, 1999).

<sup>14</sup>If we consider the effect of each  $\rho_k$  on  $P_j$  as well, then the price elasticity will be:  $(2\beta-1)/(2(\beta-1))$ .

Equation (3) indicates that an increase in the committed network size  $B_j$  induces a greater variety since  $\beta > 1$  as shown in Park (2002).<sup>15</sup> Hence, a variety of software products will be greater than the equilibrium variety without subsidization if the hardware producer commits to a network size,  $B_j$ , greater than the actual number of users,  $q_j$ .

Software producers, however, will lose from producing an excessive variety of software products. In this case, the market demand for software product  $k$ ,

$$z_k^* = \sum_{i=1}^{q_j} z_{ik} = q_j z_{ik},$$

will be smaller than the committed demands,  $z_k = \sum_{i=1}^{B_j} z_{ik} = B_j z_{ik}$ . Since  $(\rho - s)z_k - F = 0$ ,  $(\rho - s)z_k^* - F < 0$ . In other words, for the provision of a variety of software products greater than supported without subsidization, the actual number of users of the hardware product is not sufficient for the software producers to recover their development costs,  $F$ . Note that software producers will have positive profits if  $B_j < q_j$ . Hence a firm cannot credibly commit to  $B_j$  less than  $q_j$  since positive profits from producing software products will induce entry. If  $B_j > q_j$ , the loss of the production of  $K_j$  available software products is:  $K_j \{F - (\rho - s)z_k^*\} = K_j(\rho - s)(z_k - z_k^*)$ . This is the amount of subsidy necessary to compensate for software producers' losses from producing an excessive variety of software products. The hardware producer can pay this amount of subsidy either to purchase over-supplies of software products or to share the software development costs with software producers. Using the equilibrium sales of each software product in (2), we can derive the subsidy function for  $B_j \geq q_j$  as follows:

$$(4) \quad L(B_j, q_j) = K_j(\rho - s)(z_k - z_k^*) = mB_j(B_j - q_j),$$

where  $m = \frac{\beta-1}{F} s \{\beta s(2\beta-1)\}^{-(2\beta-1)/(\beta-1)}$ .

Note that  $m > 0$  since  $\beta > 1$ . Equation (4) indicates that the rate of the increased subsidy caused by an increase of  $B_j$  is '2m', which will be called the *marginal increase of subsidy* in this paper.<sup>16</sup>

Substituting both the equilibrium sales of available software products in (2) and the equilibrium sales of the outside alternative into the utility function in

<sup>15</sup>" $\beta > 1$ " guarantees concavity of the utility function in the number of software products, and is sufficient to ensure that the marginal rate of substitution between  $q_{i0}$  and  $Z_{ij}$  is decreasing.

<sup>16</sup>That is,  $\partial^2 L(B_j, q_j) / \partial B_j^2 = 2m$ .

(1),<sup>17</sup> we can rewrite the expected utility function for the bundle of hardware product  $j$  and its available software in Assumption 1 as follows:

$$(5) \quad V_{ij} + y_i - p_j + \kappa B_j,$$

where  $\kappa = \frac{\beta-1}{F} (2+s)(\beta s)^{-\beta/(\beta-1)} (2\beta-1)^{-(2\beta-1)/(\beta-1)}$ .

Note that  $\kappa > 0$  since  $\beta > 1$ . Equation (5) shows that the expected utility function for the bundle of hardware product  $j$  and its available software is increasing and linear in the committed network size  $B_j$ . We will call ' $\kappa B_j$ ' the network benefit function and  $\kappa$  the *marginal network benefit*. The procedure leading to the expected utility function in (5) indicates that the consumer's benefit from an extra variety of software products induced by an increased demand for a hardware product can be captured in the (linear) network benefit function. It is noteworthy that even in the case that the network benefit is linear in the network size, the network benefit is concave in the variety of available software (see equation (3)).

Equations (4) and (5) indicate that to a linear network benefit function, the corresponding subsidy function has a quadratic form. Comparison of the marginal network benefit,  $\kappa$ , in (5) and the marginal increase of subsidy,  $2m$ , in (4) leads to the following lemma.

*Lemma 1.* The marginal network benefit,  $\kappa$ , is greater than the marginal increase of subsidy,  $2m$ .

Note that the values of both  $m$  and  $\kappa$  depend on the software producer's marginal and fixed development costs and the parameter of the consumer's utility function.

### 3. Subsidization in the presence of indirect network externalities

We begin by analyzing a monopolist hardware producer's optimal subsidization level and two (un-integrated) hardware firms' equilibrium subsidization levels. Then, based on these analyses, we will discuss the integrated firm's strategic choice faced by a potential entrant in section 4. Recall that in the beginning of the third stage, consumer  $i$ 's expected utility function for the bundle of hardware product  $j$  and its available software is given by:  $V_{ij} + y_i - p_j + \kappa B_j$  in (5).

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<sup>17</sup>The equilibrium sales of the outside alternative are obtained from the equilibrium sales of software products in (2) and the budget constraint in (1).

### 3.1 Monopolist hardware producer

Let firm 1 be the monopolist hardware producer, and  $\phi_1 = p_1 - \kappa B_1$ . For notational simplicity, let  $R_i = V_{i1} + y_i$  and assume  $R_i$  is uniformly located between minus infinity and  $A (> 0)$  as in Katz and Shapiro (1985). Then the consumer's expected utility function implies that only those consumers for whom  $R_i \geq \phi_1$  will purchase the hardware product in the third stage. Then there are  $A - \phi_1$  such consumers, and the sales of the hardware product will be:  $q_1 = A + \kappa B_1 - p_1$ . A type  $R_i$  consumer expects to derive surplus of  $(R_i + q_1 - A)$  from purchasing a hardware product. Therefore, consumers' expected surplus is:  $S(q_1) = \int_{A-q_1}^A (\rho + q_1 - A) d\rho = q_1^2 / 2$ . Note that consumers' expected surplus increases with the monopolist's output level. The monopolist hardware producer receives a price:  $p_1 = A + \kappa B_1 - q_1$ , and earns:  $q_1(A - q_1 + \kappa B_1 - c_1)$ , where  $c_1 (< A)$  denotes the marginal production cost. Then, for any committed network size, say  $B_M$ , we can solve the first order condition of the hardware producer's profit maximization and equilibrium output levels, say  $q_M$ <sup>18</sup>. The first order condition is written as follows:

$$(6) \quad 2q_M = A + \kappa B_M - c_1.$$

Hence the equilibrium price, say  $p_M$ , will be  $p_M = q_M + c_1$ . For the existence of equilibrium, however, the network externality must not be very large. If the network externality is too large, an increase of the revenue resulting from the expected increase in the network size will be infinity. In our specification of the linear network benefit function,  $\kappa$  must be less than one for the existence of equilibrium.

*Assumption 2.*  $\kappa < 1$ .

The monopolist hardware producer decides whether and how much he/she will commit to subsidize software producers for the provision of an excessive variety of software products. If the hardware producer decides not to subsidize, then the expected network size is equal to the equilibrium sales (or the actual network size) of the product in a rational expectations equilibrium. Let superscript “\*” indicate an equilibrium value without any subsidization. Then  $B_M = q_M^*$  without any strategic subsidization. From the first order condition in (6), we can calculate the equilibrium sales without any subsidization as follows:

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<sup>18</sup>If the monopolist commits to subsidization and chooses an optimal output level simultaneously, then the optimal output level will be  $q_M^{\$}$  in Figure 1.

$$q_M^* = (A - c_1)/(2 - \kappa).$$

Let superscript “c” indicate an equilibrium value with pre-commitment to subsidization. For a pre-committed network size  $B_M$ , we can calculate the equilibrium sales as follows:  $q_M^c = (A - c_1 + \kappa B_M)/2$ . Comparing  $q_M^c$  with  $q_M^*$ , we have the following lemma.

*Lemma 2.* (i)  $q_M^c \geq q_M^*$  if and only if  $B_M \geq q_M^*$ ; and (ii)  $B_M \geq q_M^*$  if and only if  $B_M \geq q_M^c$ .

$$\begin{aligned} \text{Proof. (i) } q_M^c \geq q_M^* &\Leftrightarrow (A - c_1 + \kappa B_M)/2 \geq (A - c_1)/(2 - \kappa) \\ &\Leftrightarrow B_M \geq (A - c_1)/(2 - \kappa) \Leftrightarrow B_M \geq q_M^*. \end{aligned}$$

$$\begin{aligned} \text{(ii) } B_M \geq q_M^* &\Leftrightarrow B_M \geq (A - c_1)/(2 - \kappa) \Leftrightarrow 2B_M \geq (A - c_1 + \kappa B_M) \\ &\Leftrightarrow B_M \geq q_M^c. \end{aligned}$$

*QED*

Lemma 2 implies that if the pre-committed network size is greater than the equilibrium sales, then the equilibrium sales with this subsidization are greater than those without subsidization.

The hardware producer will commit to subsidize software producers as long as his/her marginal benefit from the subsidization is greater than or equal to the marginal cost of the subsidization. In other words, if the monopolist decides to commit to subsidize in the first stage, he/she will commit to a network size  $B_M$  to maximize:  $\Pi_M = (q_M^s)^2 - L(B_M, q_M^s)$ . As shown in (6), an increase in  $B_M$  will raise the monopolist equilibrium output level and thus the profits. On the other hand, an increase in  $B_M$  will require more subsidization to software producers. From the first order condition of this maximization problem, we can solve for  $B_M$  as follows:

$$(7) \quad B_M = (A - c_1)(\kappa + m) / \{2m(2 - \kappa) - \kappa^2\}.$$

As discussed in section 2, both  $\kappa$  and  $m$  have positive values. Hence, the numerator of (7) has a positive value. The second order condition of this maximization condition requires that the denominator of (7) also have a positive value. The failure of the second order condition implies that the marginal increase of subsidy,  $2m$ , is too small (compared to the network benefit), and thus the hardware producer will pre-commit to  $B_M = \infty$ .

We now check whether  $B_M$  in (7) is greater than  $q_M^c$ . Since  $q_M^c = (A - c_1 + \kappa B_M)/2$  from (6), we can conclude that  $B_M$  is greater than  $q_M^c$  if  $m$  is less than  $2\kappa/(2 - \kappa)$ . This condition holds since  $2m < \kappa$  as shown in lemma 1.

In other words, in our model, the marginal subsidy does not increase too fast (compared to the marginal network benefit), and thus the hardware producer will make a commitment  $B_M$  greater than  $q_M^c (> q_M^*)$ .

*Lemma 3.*  $q_M^c < B_M < \infty$ .

Lemma 3 combined with lemma 2 leads to the following proposition.

*Proposition 1.* A monopolist hardware producer always has an incentive to subsidize for the provision of a greater variety of software products than supplied without subsidization.

Since consumer surplus increases with the equilibrium output level as discussed above, this subsidization will enhance consumer surplus as well. However, the hardware producer's marginal benefit from a greater variety of software products does not count for an increase in consumer surplus and thus is smaller than the social marginal benefit. Hence the hardware producer's subsidization will not be sufficient to achieve an efficient outcome. Let  $\Phi_1$  be a fixed development cost of the hardware product. The socially optimal level of subsidization will maximize:  $TS = \Pi_M + S(q_M^c) - \Phi_1 = (q_M^c)^2 - L(B_M, q_M^c) + (q_M^c)^2 / 2 - \Phi_1$ .<sup>19</sup> Then the socially optimal level of subsidization will be:<sup>20</sup>

$$(8) \quad B^e = (A - c_1)(3\kappa + m) / \{2m(2 - \kappa) - 3\kappa^2\}.$$

It is easy to check that  $B^e > B_M$  from (7) and (8).

*Proposition 2.* The monopolist's subsidization increases not only the monopolist's profits but also consumer surplus. However, the monopolist's subsidization is smaller than the socially optimal level of subsidization.

### 3.2 Duopoly without integration

Now consider the duopoly case in which no hardware firm is integrated with software producers. We assume that two firms, say firm 1 and firm 2, produce

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<sup>19</sup>Note that software producers earn zero profits.

<sup>20</sup>The second order condition of this maximization condition requires that the denominator of (8) has a positive value, which will be satisfied when the denominator of (7) has a positive value.

homogeneous hardware products. Then a consumer's stand-alone benefits of these two homogeneous hardware products must be the same. Let  $V_i = V_{i1} = V_{i2}$ , and  $R_i = V_i + y_i$ . Given the homogeneity of the hardware products, firm 1 and firm 2 will both have positive sales in the third stage only if the expected hedonic prices of the two hardware products are the same, i.e.,  $p_1 - \kappa B_1 = p_2 - \kappa B_2$ . Let  $\phi$  denote the common value of the hedonic prices given above. For a given value of  $\phi$ , only those consumers for whom  $R_i \geq \phi$  will purchase a hardware product. As assumed in section 3.1,  $R_i$  is uniformly located between minus infinity and  $A (> 0)$ . Then there are  $A - \phi$  such consumers, and the total sales, say  $Q$ , will be:  $Q = q_1 + q_2 = A + \kappa B_j - p_j = A - \phi$ , for  $j = 1$  and 2. Hence, hardware producer  $j$  receives a price:  $p_j = A + \kappa B_j - Q$ , and a type  $R_i$  consumer expects to derive surplus of  $(R_i + Q - A)$  from purchasing a hardware product. Therefore, consumers' expected surplus is:

$$S(Q) = \int_{A-Q}^A (\rho + Q - A) d\rho = Q^2 / 2.$$

Note that consumers' expected surplus increases with the total output level as in the monopoly case. Let  $c_j (< A)$  be the marginal cost of the production of hardware product  $j$ .

Then adapting the standard Cournot assumption, we will assume that firm 1 and firm 2 simultaneously choose  $(q_1, B_1)$  and  $(q_2, B_2)$  to maximize their own profits, taking the other's as given. Firm 2's profit is given by:

$$\Pi_2 = (p_2 - c_2)q_2 - L(B_2, q_2) = (A - q_1 - q_2 + \kappa B_2 - c_2)q_2 - mB_2(B_2 - q_2).$$

From the first order condition of firm 2, we have:

$$(9) \quad 2mB_2 - (\kappa + m)q_2 = 0, \text{ and } A - c_2 - 2q_2 - q_1 + (\kappa + m)B_2 = 0.$$

Then, the firm 2's reaction function is obtained as follows:

$$(10) \quad q_2 = \frac{2m}{4m - (\kappa + m)^2} (A - c_2) - \frac{2m}{4m - (\kappa + m)^2} q_1.$$

The second order condition of this maximization problem implies that  $4m - (\kappa + m)^2 > 0$  in (10), which holds due to lemma 1. By symmetry, we can obtain firm 1's reaction function as well. Figure 1 illustrates both firms' reaction curves and the equilibrium output levels, say  $(q_1^s, q_2^s)$ , which satisfies firm 1's and firm 2's first order conditions simultaneously.

For the welfare evaluation of these subsidizations, consider a (counterfactual) situation in which the subsidization between hardware and software

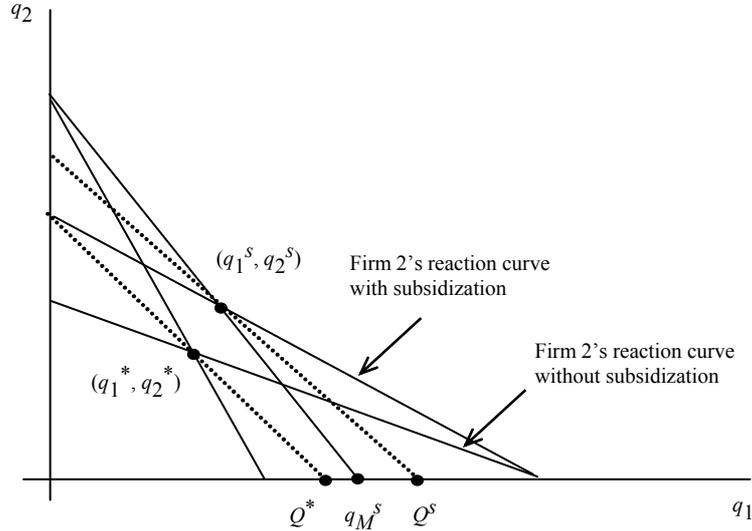


Figure 1. Effects of subsidization ( $Q^* < Q^s$ )

producers is not allowed (by law or other means). Let superscript “\*” indicate an equilibrium value without any strategic subsidization. Then  $B_j = q_j^*$  for  $j = 1$  and 2 in a rational expectations equilibrium, and the firm 2’s reaction function will be:

$$(11) \quad q_2 = \frac{1}{2-\kappa}(A-c_2) - \frac{1}{2-\kappa}q_1.$$

Firm 1’s reaction function can be obtained by symmetry. Let  $(q_1^*, q_2^*)$  denote the equilibrium sales of firm 1 and firm 2 in this case. We can check that the absolute value of the slope of each firm’s reaction curve without subsidization is smaller than that with strategic subsidization. Hence it is easy to show graphically (rather than analytically) that  $q_j^s > q_j^* (j=1,2)$  and  $Q^s = q_1^s + q_2^s > Q^* = q_1^* + q_2^*$  (refer to Figure 1). Let  $B_j^s$  be the committed network size in equilibrium. Then, from the first order condition in (9), we have:  $B_j^s = q_j^s(\kappa + m)/2m$ . Note that  $B_j^s > q_j^s$  since  $2m < \kappa$ . In other words, each un-integrated hardware firm will subsidize for the provision of a greater variety of software products than supplied without subsidization. Hence, we have the following proposition.

*Proposition 3.* In the duopoly equilibrium, un-integrated hardware producers always have incentives to subsidize software producers for the provision of

greater varieties of software products than supplied without subsidization. Furthermore, these subsidizations raise the total sales and thus consumer surplus.

#### 4. Integration and first-mover advantage

Suppose now that an integrated monopolist, say firm 1, is faced by a potential entry of an un-integrated hardware producer, say firm 2. We assume that both firms will produce homogeneous hardware products. Then a consumer's stand-alone benefits of these two homogeneous hardware products must be the same. Let  $V_i = V_{i1} = V_{i2}$ , and  $R_i = V_i + y_i$ . As assumed in section 3,  $R_i$  is uniformly located between minus infinity and  $A(>0)$ .

Suppose that firm 2 enters in the second stage. Then, for a given incumbent's commitment  $B_1$ , we can solve the first order condition of the two hardware producers' profit maximization behavior in the third stage, adapting the standard Cournot assumption. Let  $\Phi_2$  denote a fixed start-up cost of firm 2. In the third stage, the incumbent, firm 1, will choose  $q_1$  to maximize:  $(p_1 - c_1)q_1 = (A - q_1 - q_2 + \kappa B_1 - c_1)q_1$ . Then, from the first order condition, the firm 1's reaction function is obtained as follows:

$$(12) \quad q_1 = (A - c_1 + \kappa B_1) / 2 - q_2 / 2.$$

On the other hand, the entrant, firm 2, will choose  $q_2$  and  $B_2$  to maximize:  $\Pi_2 = (p_2 - c_2)q_2 - mB_2(B_2 - q_2) = (A - q_1 - q_2 + \kappa B_2 - c_2)q_2 - mB_2(B_2 - q_2)$ . Then, the firm 2's reaction function is obtained as in (10). Figure 2 illustrates the incumbent's and the entrant's reaction curves. If the incumbent is not integrated and thus cannot commit to  $B_1$  in advance, then the equilibrium output levels will be  $(q_1^s, q_2^s)$  as discussed in section 3. Note that the absolute value of the slope of firm 1's reaction curve is smaller than that of firm 2's, which is again smaller than one.

With the first-mover advantage in strategic subsidization, the incumbent can choose either to accommodate or to deter the entry by enhancing the applications barrier to entry. If firm 1 decides to accommodate an entry, it will commit to  $B_1$  in the first stage to maximize  $\Pi_1 = (q_1)^2 - L(B_1, q_1)$ , taking account of the firm 2's reaction function. Graphically, the optimal  $B_1$  is set to produce  $q_1$  at which the firm 1's iso-profit curve is tangent at the firm 2's reaction curve as in the Stackelberg case. Hence, if firm 1 accommodates the entry, then it will commit to a certain level of  $B_1$  in order to induce the duopoly equilibrium at  $(q_1^c, q_2^c)$  in Figure 2. It is obvious that  $Q^c = q_1^c + q_2^c > Q^s = q_1^s + q_2^s$  from Figure 2. Figure 2

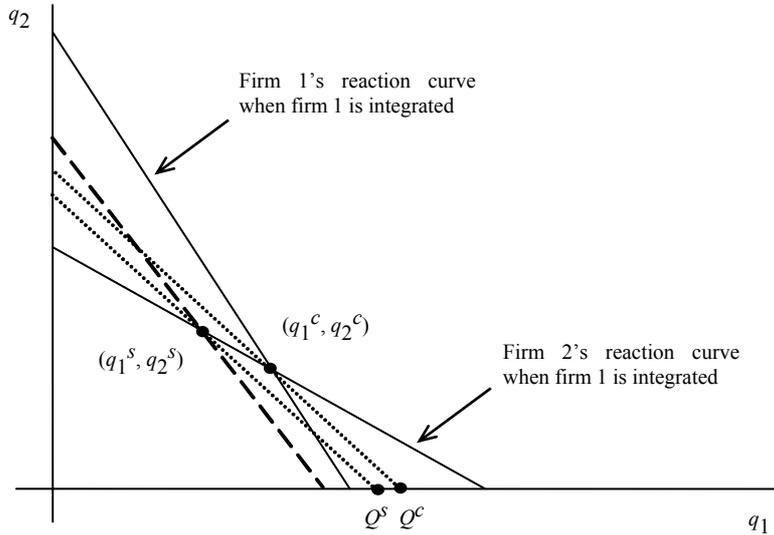


Figure 2. Accommodated entry ( $Q^s < Q^c$ )

also indicates that firm 1’s ability to commit to  $B_1$  in advance increases the equilibrium output level (and thus profit) of firm 1 but decreases the equilibrium output level (and thus the profit) of firm 2. Hence, we have the following proposition.

*Proposition 4.* When an integrated incumbent accommodates the entry of an un-integrated hardware producer, the equilibrium industry output level and consumer surplus are greater than those of the duopoly without integration.

Suppose now that the integrated incumbent decides to deter the entry instead of accommodating it. Let  $q_1^d$  denote the incumbent’s output level when the entry is deterred. Then the incumbent will commit to  $B_1^d$  in the first stage to produce  $q_1^d$ . It is obvious that the incumbent will pre-commit at least to  $B_M$  in (7) and produce the monopoly output level  $q_M^c$  in section 3. That is,  $q_1^d \geq q_M^c$ .<sup>21</sup> The first-mover advantage of the integrated firm leads to the following unusual observation: depending on the values of  $\kappa$  and  $m$ , it is possible that  $q_M^c > Q^s$ . Since the analytical comparison is quite complicated, we instead provide a graphical illustration of this possibility in Figure 3. As indicated in Figure 3, the monopoly output level of the integrated firm can be greater than the industry output level of un-integrated hardware firms in duopoly.

<sup>21</sup>If  $q_1^d = q_M^s$ , then the entry is blockaded.

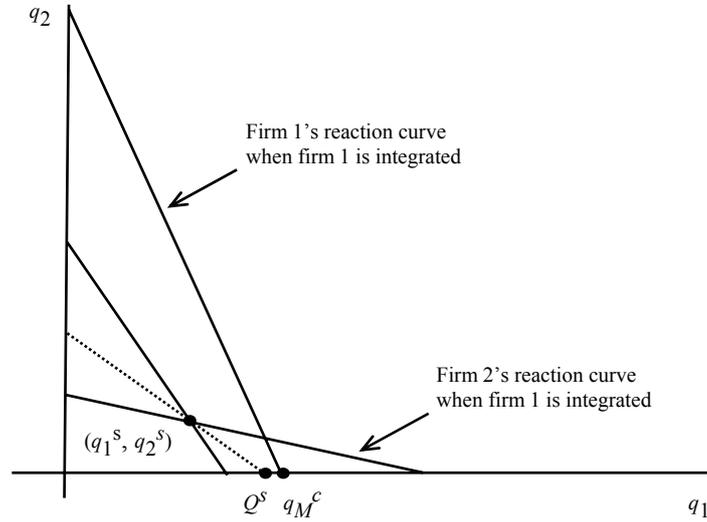


Figure 3.  $q_M^c > Q^s$

Moreover, as an entrant's start-up cost gets smaller, an incumbent has either to accommodate the entry or to increase its output level to deter the entry. Let  $q_2^d$  denote the entrant's best response to  $q_1^d$ . Then at  $(q_1^d, q_2^d)$ , the entrant's profit must be equal to the start-up cost, i.e.,  $\Pi_2^d = \Phi_2$ . It is obvious in Figure 4 that the entry-deterrence output level  $q_1^d$  decreases with the entrant's start-up cost. Recall that consumer surplus increases with the total output level.

Hence we conclude as follows:

*Proposition 5.* Even when an integrated incumbent deters the entry of an un-integrated hardware producer, the entry-deterrence output level and the corresponding consumer surplus can be greater than the industry output level and the consumer surplus of the duopoly equilibrium without integration. This conclusion is more likely to hold if the entrant's start-up cost gets smaller.

Note that our discussions in this section can be applied to the case in which there already exist an integrated firm (firm 1) and an un-integrated hardware producer (firm 2). Then the entry deterrence can be interpreted as the exit of the un-integrated hardware producer if we interpret  $\Phi_2$  as a scrap value.

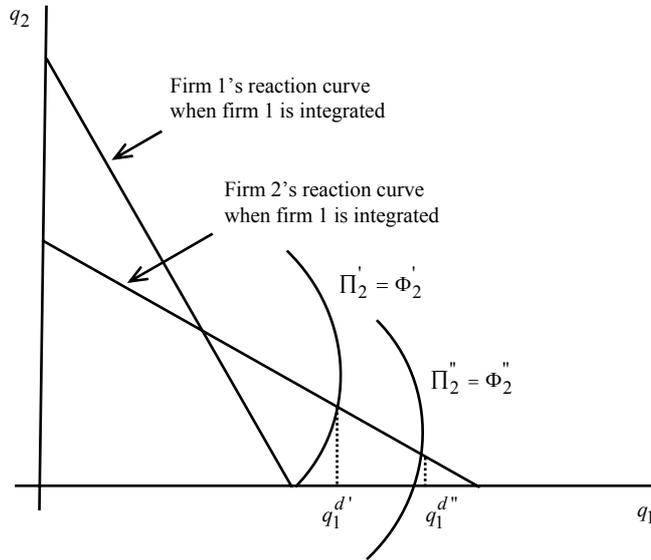


Figure 4. Deterred entry and start-up cost ( $\Phi_2' > \Phi_2''$ )

5. Conclusion

In this paper, we have analyzed welfare consequences of an integrated hardware/software firm's first-mover advantage in the subsidization for the development of software products. The breakup of the Microsoft would have deprived Microsoft of this first mover advantage in the PC market. We have shown that an integrated incumbent's pre-commitment to subsidization may constitute a strategic barrier to entry, and the breakup is more likely to induce an entry. However, consumer surplus can be higher even in the case of the deterred entry than in a post-entry equilibrium with the breakup, if the entrant's fixed start-up cost is sufficiently small. Moreover, consumer surplus is always higher in the case of the accommodated entry, and it is possible that antitrust concerns drive the incumbent to choose to accommodate the entry even if entry deterrence is more profitable.

The model developed in the paper has assumed that two producers of homogenous hardware products compete in a quantity-setting game. Will the conclusions of the paper hold in a pricing game with differentiated hardware products? In the appendix, we employ a Hotelling's model for the hardware products, showing that our conclusions of propositions 4 and 5 based on the Cournot model still hold in the Hotelling's model if the consumer's preference for product differentiation is sufficiently strong.

*Appendix*

In this appendix, we further examine whether our conclusions remain unchanged in a pricing game with differentiated hardware products. For the purpose, we employ a Hotelling's model for the hardware products. We will assume that the integrated firm has a first-mover advantage and only the integrated firm subsidizes for the provision of a greater variety of software.<sup>22</sup> In addition, for simplicity, we assume: (i) both firms have the same marginal cost, i.e.,  $c = c_1 = c_2$  and (ii) the difference in a consumer's utility due to a different income level (or deviation from the average income) is reflected in the consumer's location in the product space. Then consumer  $i$ 's (expected) utility of the bundle of a hardware product and a committed variety of available software in (5) can be rewritten as follows:

$$(A.1) \quad A - td_{i1}^2 - p_1 + \kappa B_1, \text{ and } A - td_{i2}^2 - p_2,$$

where  $A$  is a gross utility of the hardware product,  $d_{ij}$  is the distance traveled by consumer  $i$  to the location of product  $j$ ,  $t$  is a unit travel cost. Note that  $t$  indicates the degree of the consumer's preference for product differentiation. As indicated in (A.1), a greater variety of available software pre-committed by the integrated firm,  $B_1$ , works like an improved quality of the firm's product.

Then, following the typical procedure of the Hotelling's model, we can derive the two firms' demand functions as follows:

$$(A.2) \quad q_1 = (p_2 - p_1) / 2t + \kappa B_1 / 2t + 1/2, \text{ and } q_2 = (p_1 - p_2) / 2t - \kappa B_1 / 2t + 1/2.$$

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<sup>22</sup>We can show that in the Hotelling's model that follows, simultaneous subsidization is worse for both firms than no subsidization. Unlike the model presented in section 2, there is no market-expanding effect in the Hotelling's model even if both firms improve the quality of the product via greater varieties of available software. Hence, if both firms can make subsidization, more intense competition leads to lower equilibrium prices and lower profits. Moreover, we can also show that under some conditions, the un-integrated firm chooses not to subsidize when the integrated firm has a first-mover advantage in subsidization. Note that in the extended Hotelling's model of Church and Gandal (1996), the hardware producer is an exclusive provider of software products and the marginal utility (and thus the price) of an additional software product is decreasing with an additional variety of software. Hence, in the Church and Gandal (1996), the integrated firm can commit to a less variety (than that provided by independent software producers) to boost its profit.

Note that firm 2's profit is:  $\Pi_2 = (p_2 - c)q_2 - \Phi_2$ , while firm 1's profit is:  $\Pi_1 = (p_1 - c)q_1 - mB_1(B_1 - q_1) - \Phi_1$  if  $B_1 > q_1$ . Then applying the Nash equilibrium concept, we can obtain the reaction functions as follows:

$$(A.3) \quad p_1 = p_2 / 2 + (\kappa - m)B_1 / 2 + (t + c) / 2, \text{ and } p_2 = p_1 / 2 - \kappa B_1 / 2 + (t + c) / 2.$$

Then solving these two reaction functions simultaneously, we obtain the equilibrium prices, say  $p_1^H$  and  $p_2^H$ , as follows:

$$(A.4) \quad p_1^H = (\kappa - 2m)B_1 / 3 + (t + c), \text{ and } p_2^H = -(\kappa + m)B_1 / 3 + (t + c).$$

Substituting these prices into the demand functions in (A.2), we now obtain the equilibrium sales, say  $q_1^H$  and  $q_2^H$ , as follows:

$$(A.5) \quad q_1^H = (\kappa + m)B_1 / 2t + 1/2, \text{ and } q_2^H = -(\kappa + m)B_1 / 2t + 1/2.$$

Since  $\kappa > 2m$  as shown in lemma 1, we conclude as follows.

*Lemma A.1.* If  $B_1 > q_1^H$ , then  $p_1^H > t + c > p_2^H$  and  $q_1^H > 1/2 > q_2^H$ .

Since a greater variety of available software pre-committed by the integrated firm,  $B_1$ , works like an improved quality of the firm's product, it increases the integrated firm's price (of the hardware product) but decreases the un-integrated hardware producer's price (see Figure A.1).

Furthermore, despite these changes of equilibrium prices, the positive effect of the increased variety of software products dominates, and thus the equilibrium sales of the integrated firm rise but those of the un-integrated hardware producer fall if the integrated firm commits to a higher  $B_1$ . Hence, if  $B_1$  is sufficiently large, the un-integrated firm's profit will fall below zero (i.e.,  $\Pi_2 = (p_2 - c)q_2 - \Phi_2 < 0$ ). In other words, as in the Cournot case, the integrated firm commits to a certain level of  $B_1$  to deter the entry of the un-integrated firm. On the other hand, the integrated firm, if more profitable, will choose  $B_1$  to accommodate the entry, maximizing:  $\Pi_1 = (p_1^H - c)q_1^H - mB_1(B_1 - q_1^H) - \Phi_1$ . The optimal  $B_1$ , say  $B_1^H$ , is:

$$(A.6) \quad B_1^H = 2t(\kappa + m) / (6tm - (m + \kappa)^2).$$

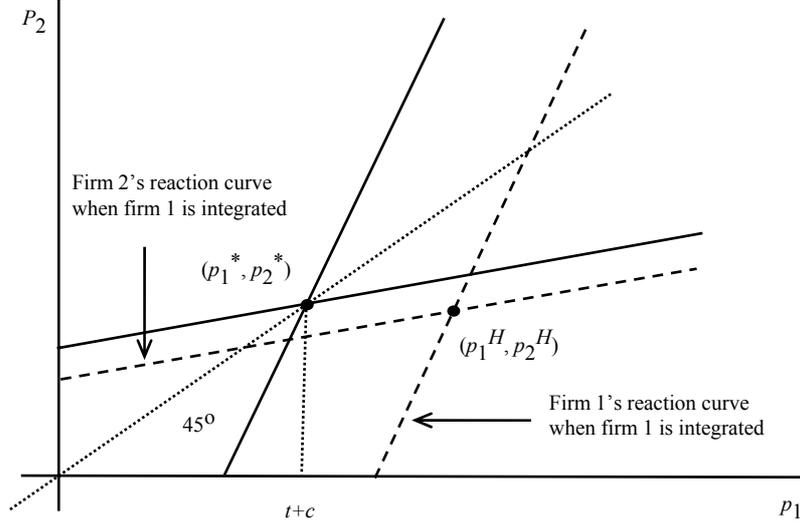


Figure A.1. Effects of subsidization ( $p_2^H < p_2^* = p_1^* < p_1^H$ )

(A.6) indicates that  $B_1^H > 0$  if  $t > (m + \kappa)^2 / 6m$ , which is also a sufficient condition for  $B_1^H > q_1^H$ . Note that lemma A.1 holds if  $B_1^H > q_1^H$ . Hence we can summarize as follows.

*Proposition A.1.* The integrated firm can deter the entry of the un-integrated firm by committing to a sufficiently large  $B_1$ . When the integrated firm accommodates the entry, the firm commits to  $B_1$  greater than the equilibrium sales if the consumer's preference for product differentiation is sufficiently strong (i.e.,  $t > (m + \kappa)^2 / 6m$ ).

We now proceed to discuss the welfare consequences of the integrated firm's commitment to a greater variety of available software products. Despite an induced increase of the integrated firm's price, this greater variety itself dominates the increase of the integrated firm's price in all the consumers' utilities defined in (A.1). Note that, as indicated in Figure A.2,  $A - p_1^H + \kappa B_1 = A - t - c + (2/3)(\kappa + m)B_1$ . In addition, as shown in lemma A.1, the integrated firm's commitment to a greater variety of available software products lowers the un-integrated firm's price. Therefore, we can infer that a greater variety of available software pre-committed by the integrated firm will raise consumer surplus. Moreover, since the un-integrated firm's profit is decreasing in  $B_1$ , the integrated firm will commit to a higher  $B_1$  to deter the entry if the un-integrated firm's start-up cost gets smaller.

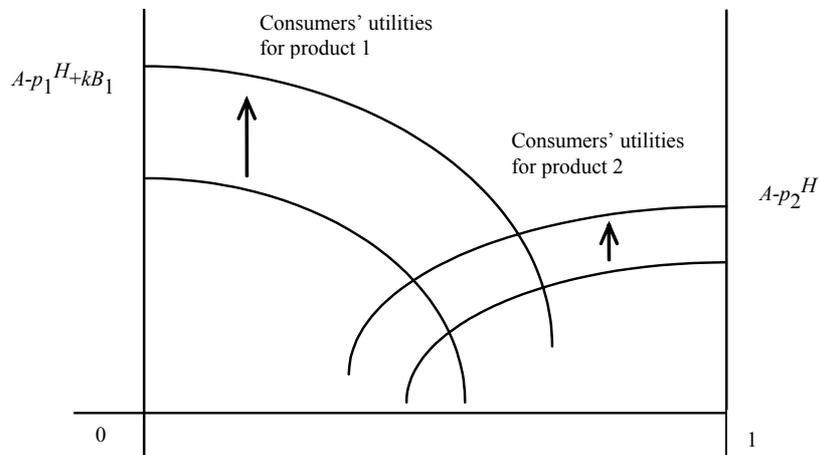


Figure A.2. Effects of subsidization on consumer surplus when  $B_1$  increases

*Proposition A.2.* If an integrated incumbent accommodates the entry of an un-integrated hardware producer, consumer surplus will increase. Even when an integrated incumbent deters the entry of the un-integrated hardware producer, consumer surplus can be greater than that of the duopoly equilibrium with no integration if the entrant's start-up cost is sufficiently low.

Therefore, our conclusions of propositions 4 and 5 based on the Cournot model still hold in the Hotelling's model.

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