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# INTEGRATION, COMPLEMENTARY PRODUCTS AND VARIETY

by

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# Integration, Complementary Products and Variety

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**Abstract**

*This paper examines the incentives for integration when the market for both consumer durables and supporting or complementary services is oligopolistic. We find that the equilibrium industry structure will depend on the value that consumers place on variety. If the value of additional software is relatively small, the equilibrium industry structure is for both hardware firms to remain unintegrated, while if the value of additional software is relatively large, the equilibrium industry structure is for both hardware firms to integrate.*

*Under the integrated industry structure, profits are lower, less varieties are provided, and hardware prices are lower than under the unintegrated industry structure. The game has a prisoners' dilemma structure when consumers place a high value on the variety of software. This is due to a foreclosure effect.*

*Although consumer surplus is higher under an integrated industry structure, the total surplus associated with the unintegrated industry structure exceeds that of the integrated industry structure.*

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## 1. Introduction

The benefit from consuming durables often depends on the consumption of supporting or complementary goods. The greater the variety of compatible complementary goods, the "software," the greater the value of the services rendered by the capital good, the "hardware," and hence the greater the willingness of a consumer to pay for the hardware good. Examples include many consumer electronic durables such as televisions, video cassette recorders, video games and personal computers.

In Church and Gandal (1989) we examined the issue of intertemporal standardization, focusing our attention on the strategic pricing behavior of hardware vendors. Church and Gandal (1990) examined the strategic decision of software firms concerning which technology to provide software for. In both of these settings we ruled out integration and assumed that hardware firms could not provide their own software. While we did not explore the reason for this restriction, it corresponded to the actual industrial organization of many of the markets in which we were interested.

However, there has been a recent trend towards integration in some industries. Perhaps the most significant developments are Sony's acquisition of Columbia Pictures Entertainment and CBS Records for $3.4 and $2 billion, respectively (Business Week, 10/09/89), and Matsushita's purchase of MCA for $6.6 billion (Economist, 12/01/90). Philips, the Dutch electronics giant, owns 80 percent of Polygram Records (Economist, 8/11/90). Thus, of the six major record companies in the world, three are now owned by consumer electronic firms.[1]

On the other hand, there are other industries where integration is not so extensive. For example the personal computer industry is relatively unintegrated. While Apple Computer has its own small software subsidiary, most of the significant suppliers of software (Lotus, Adobe and Microsoft to name a few) are not owned by the major

[1]Moreover, Toshiba recently acquired a minority stake in Time-Warner (Economist, 11/2/91).

hardware firms (IBM and Apple).

A natural question to ask is why some durable good producers integrate into the provision of their supporting services and why others remain unintegrated. It has been suggested that integration into software is a defensive move on the part of hardware firms to avoid being foreclosed from software.[2]

In this paper, we consider oligopoly markets in both hardware and complementary software and ask under what conditions an integrated industry structure will emerge and what are the welfare implications of integration. We address these questions by considering the decision by hardware firms to integrate as part of a multistage game. In our framework, the structure of the industry is endogenous. There are two hardware firms that produce a differentiated product. The decision of a hardware firm to integrate or not is modelled as a decision to "allow" an independent software industry or not.

If a hardware firm integrates, it is the exclusive supplier of software and it is able to commit to the number of software varieties before price competition occurs.[3] The decision to integrate can be interpreted as a decision to make the system compatible or incompatible with software provided by independent firms.[4] Alternatively, the effect of integration in our setting makes the decision to integrate similar to a decision to tie software to hardware.[5]

[2]It has been claimed that Sony was motivated to acquire Columbia and CBS to avoid a similar fate befalling its new generations of audio-visual equipment as befell its Beta video cassette recorder. Sony believes that the demise of its Beta technology was in part attributable to the software industry not providing sufficient compatible software (Economist, 4/13/91).

[3]In Section 5, we show that relaxing the "exclusivity" assumption does not qualitatively change our results. Moreover, the assumption is not very restrictive. As Mathewson and Winter (1984) and Perry and Groff (1985) show for the monopoly case, the vertically integrated outcome with exclusion can be duplicated through the use of vertical restraints. The same logic applies here. In our setting, the hardware firm needs two instruments: one to limit entry and a second to extract rents. Nintendo, for example, strictly controls the number of video games available for its system. It does this by limiting access to the required cartridges (Economist, 2/24/90).

[4]We thank Nicholas Economides for this interpretation.

[5]The tied good is software and the tying good is hardware.

If a hardware firm does not integrate, it does not provide any software. In this case, there is free-entry into the provision of software and software is provided by a dedicated industry. Each software firm is capable of producing a single incompatible product, i.e., a software product written for one technology will not work with the other technology.[6,7]

We show that the equilibrium industry structure will depend on the value that consumers place on the variety of software and the fixed costs of software development. Holding the fixed costs of software development constant, if the value placed on software variety is small, the equilibrium industry structure is unintegrated, i.e., neither firm integrates; if the value placed on software variety is large, the equilibrium industry structure is fully integrated, i.e., both firms integrate. When the value placed on software variety falls in an intermediate region, both structures (full integration and no integration) are equilibria.

Under the integrated industry structure, profits are lower, less varieties are provided, and hardware prices are lower than under the unintegrated industry structure. Prices are lower under an integrated industry structure because the hardware firms internalize a pricing externality when they integrate. In the unintegrated structure, hardware firms do not take into account that a larger market share, engendered by a lower hardware price, increases the sales and profits of software firms.

Relative to the unintegrated industry structure, two opposing factors determine the number of software varieties that a hardware firm will provide in the integrated industry structure. By increasing the number of software varieties available for its hardware technology, a hardware firm increases the attractiveness of its technology and hence its market share. This demand effect is more than offset, however, by

[6]At least not without incurring the fixed costs of "porting" the software over to the other format. Lotus 123 was developed for the IBM PC and compatibles. Despite several years and a significant capital investment, Lotus has only recently succeeded in developing a version of 123 for the Macintosh.

[7]See Chou and Shy (1990) for a discussion of partial compatibility.

the incentive to mitigate hardware price competition in the integrated structure by reducing the number of software varieties. As a result, in equilibrium the integrated hardware firms provide less software varieties than are provided under the unintegrated industry structure.

However, this strategy is only partially successful as equilibrium hardware prices in the integrated structure are lower than in the unintegrated industry structure and consequently, profits are lower under an integrated industry structure.

When consumers place a high value on software variety, the game has a prisoners' dilemma structure, since the equilibrium industry structure is integrated. This is due to a foreclosure effect. An integrated firm, by both lowering the prices of software and hardware and by increasing the variety of software, expands its market share and thus decreases the market share of its unintegrated rival. This decrease in the size of the unintegrated rival's network, reduces the profitability of providing software and hence the number of software firms which provide software declines, further reducing the attractiveness of the unintegrated network. In the extreme case, the integrated firm completely forecloses the software access of its unintegrated rival by providing enough software so that the equilibrium market share of the unintegrated technology is zero. When consumers place a high value on software variety, the number of software varieties required to foreclose is relatively small, making this strategy inexpensive. In order for the unintegrated technology to survive, it must integrate as well.

There is a trade off between the magnitude of the fixed costs of software and the preferences of consumers for software variety. The smaller the fixed costs of software development, the smaller the marginal benefit of an additional software variety required for the game to have the structure of the prisoners' dilemma.

Consumer surplus is higher under an integrated industry structure. The increase in hardware price competition between the integrated firms more than compensates for the reduced variety of software. Nevertheless, the total surplus of the unintegrated industry structure always exceeds that of the integrated industry structure; the higher consumer surplus is not large enough to offset the lower profits.

Economides and Salop (1991) consider a situation where there are two components, with multiple (exogenous) brands of each component. The two components are complementary and consumed in fixed proportions. They show that integration among pairs of components results in the lowest prices to consumers among the number of different integration structures considered, due to the internalization of the same pricing externality at work in our setting. Our framework differs from theirs in that we consider a setting where the variety of complementary products is important and the integrated structure is determined endogenously.

Our setting is also related to the literature on endogenous integration and on foreclosure. Lin (1988) and Bonanno and Vickers (1988) show that the endogenous vertical structure that emerges in the "manufacturer-retailer paradigm" is vertical "disintegration" or separation. By setting a transfer price above marginal cost, manufacturers can strategically take advantage of the double marginalization problem to mitigate price competition at the retail level, thereby increasing profits. A similar effect is at work in our setting; the pricing externality between software and hardware gives an integrated firm an incentive to price more aggressively. When foreclosure is difficult, the equilibrium in our setting is also separation. However, when foreclosure is inexpensive, we find that integration is the equilibrium industry structure.

Several authors have recently addressed the incentives for vertical integration when foreclosure gives a competitive advantage by raising the costs of rivals.[8] However, as Ordover and Saloner (1989, p. 570) note, little if any attention has been paid to the issue of demand side foreclosure. The exception is Whinston (1990). Our foreclosure effect is an extension of Whinston's "strategic foreclosure." Whinston considers a number of examples in which a multiproduct firm is a monopoly in one market and a

[8]See Salinger (1988), Hart and Tirole (1989), and Ordover, Salop and Saloner (1990).

duopolist in another. He shows that in certain instances the monopolist can extend its market power into the second market by tying. The mechanism by which this works is foreclosure: by tying, the monopolist reduces the market share and profits of its rival, potentially forcing it out of the market. In our setting, when an integrated firm is competing with an unintegrated rival, it takes into account that increasing the number of software varieties will enhance the consumption benefits of its technology and reduce the extent of, i.e., foreclose, the software market for its unintegrated rival. The integrated hardware firm is able to extend its monopoly in software into the hardware market and in extreme cases can become a monopolist in hardware.[9]

The plan of the paper is as follows. In section 2, we specify technology and the preferences of consumers. In section 3, we solve for the equilibrium industry structure. Section 4 addresses the welfare implications of different industry structures. Section 5 offers a brief conclusion and discusses the setting where integration does not preclude the supply of independent software.

## 2. The Model

In this section we develop a simple model. We begin by describing technology.

### 2.1 Technology

We assume that the two hardware technologies are incompatible. Software written or provided for one technology will not work with the other. For simplicity, we assume that the marginal cost of producing hardware and software for either technology is equal to zero. A developer of a software variety must incur a fixed cost, denoted F. The locations of the two hardware technologies, denoted A and B, are exogenously fixed. Let technology A be at the left-end point and technology B be at the right-end

[9] This result goes through even if the integrated firm is not the only supplier of software. See Section 5.

point of the unit line.

### 2.2 Preferences of Consumers

We now specify the preferences of consumers over hardware, software, and an outside good. In modelling preferences over hardware and software we explicitly recognize the following:

(*i*) The value of hardware depends on the availability of software. Without the provision of compatible software, hardware provides no consumption benefit.

(*ii*) The greater the variety of software, the greater the benefit or value of a hardware technology. However, the marginal value of additional software is decreasing.

(*iii*) The demand for both hardware and a variety of software is perfectly inelastic.

From (*iii*) consumers purchase only one unit of hardware and one unit of a variety of software. However, from (*ii*) they will, in general, purchase more than one variety of software.

We assume that the benefit consumers receive from consuming $N$ varieties of software is given by $N^{\beta}$. We restrict $\beta < 1/2$, though (*ii*) above only requires $\beta < 1$.[10] The preferences of consumers for hardware are represented using an address model. The tastes of consumers are distributed uniformly along a line of unit length, the population is normalized to one, and all consumers have income $y$. The consumption of a hardware technology different from the most preferred type imposes a utility cost on the consumer that is equal to the distance separating the two types. The utility

[10] The more stringent assumption ensures that standardization on one technology is never an equilibrium of the subgame in which both hardware technologies are integrated. See footnote (16).

function of a consumer located distance $t$ from hardware $i$ is therefore[11]

$$U_i = N_i^{\beta} + x - t, \tag{1}$$

where $N_i$ is the number of software varieties consumed and $x$ is consumption of the outside good.

The budget constraint for a consumer is:

$$\sum_{j=1}^{N} \rho_{ji} + x = y - p_i, \tag{2}$$

where $\rho_{ji}$ is the price of a unit of software variety $j$ available for hardware technology $i$, $y$ is the income of the consumer, $p_i$ is the price of hardware technology $i$, and $N$ is the number of software varieties purchased. Maximization of (1) is a two-stage procedure. In the second stage, (1) is maximized subject to (2) for each hardware technology $i$. In this stage, the consumer selects which varieties of software and the total number of varieties to consume. Substituting this into (1) gives indirect utility for technology $i$. In the first stage the consumer selects the hardware variety for which the indirect utility is greatest.[12]

To solve the second-stage for technology $i$, rank the software varieties in ascending order by price. The marginal benefit of another software variety is $\beta N^{\beta-1}$.[13] Ignoring the integer problem, the number of varieties consumed is then implicitly defined by $\rho_N = \beta N^{\beta-1}$, where $\rho_N$ is the price of the $N^{th}$ most expensive software variety.

In other words, the consumer purchases one unit of the $N$ lowest-priced varieties, where $N$ is such that the marginal benefit of the $N^{th}$ software product equals $\rho_N$. If the marginal benefit of the $N^{th}$ software product exceeds $\rho_N$, one unit of all software varieties is consumed.

[11]Hardware only facilitates the consumption of software and doesn't directly enter into (1). However, the network benefit, $N_i^{\beta}$, is only obtained if hardware $i$ is purchased.

[12]We assume that purchase of one of the two hardware technologies is optimal.

[13]To reduce notational clutter, we temporarily drop the $i$ subscript.

We assume that consumers purchase hardware first, then software. Before considering the indirect utility or consumption benefit that a consumer receives from consuming technology $i$, we state the following lemma regarding the price of software.

**Lemma 1** *If $N$ software varieties are supplied for technology $i$, then the symmetric Nash equilibrium software price is*

$$\rho_i = \beta N_i^{\beta-1} \tag{3}$$

*Proof.* If the price of a software variety exceeds $\beta N_i^{\beta-1}$, consumers will not purchase it. A price less than $\beta N_i^{\beta-1}$ reduces profits since sales are unchanged as the demand for a variety of software is perfectly inelastic. *Q.E.D.*

In equilibrium, software is priced such that each consumer who purchased technology $i$ is just willing to purchase one unit of each software variety provided. The import of lemma (1) is that the price of software is determined solely by the number of software varieties supplied and it is a a decreasing function of the number of software varieties.

A symmetric software price equal to $\beta N_i^{\beta-1}$ means that the budget constraint can be written as $\beta N_i^{\beta} + x = y - p_i$. Solving for $x$ and substituting into (1) gives the indirect utility function for technology A:[14]

$$V_A = (1-\beta)N_A^{\beta} + y - p_A - t. \tag{4}$$

Indirect utility or the benefit of a network depends on the price of hardware and the number of software products available. A consumer located at $t$ purchases system A if the benefit from network A ($V_A$) exceeds the benefit from adopting system B ($V_B$).

[14]We measure $t$ from the left-hand endpoint.

The marginal consumer is defined implicitly by $V_A = V_B$. Using equation (4) and rearranging terms, the value for the equilibrium market share for technology A is

$$t = \frac{((1-\beta)(N_A^\beta - N_B^\beta) - (p_A - p_B) + 1)}{2}. \tag{5}$$

The equilibrium market share for technology B $(1-t)$, is similarly defined.

## 3. Endogenous Integration

### 3.1 The Timing

We consider integration as part of a stage game. The timing is as follows. In the first stage, each hardware firm makes a decision to provide software or to allow an independent software industry. The decision to integrate is equivalent in our model to the decision to be the exclusive supplier of software for the technology.

The possible industry structures are (1) unintegrated where neither hardware firm supplies software, (2) fully integrated, where both hardware firms are exclusive suppliers of software, and (3) partially integrated, where one hardware firm is integrated.

If neither firm integrates in the first stage, in the second stage hardware firms set hardware prices and the number of software firms for each hardware technology is determined by free entry.

If both firms integrate, there is an additional stage. In the second stage, hardware firms commit to the number of software varieties by incurring the fixed cost F per variety. In the third stage hardware prices are determined.

If only one of the firms integrates, the integrated hardware firm chooses the number of software varieties in the second stage. In the third stage, both hardware firms choose their hardware prices and the number of software varieties for the unintegrated hardware firm is determined by free entry. Figure 1 displays the timing of the game schematically.

INSERT FIGURE 1 ABOUT HERE

We solve for the subgame perfect equilibrium by backwards induction. To do so, we must determine the profits of each hardware firm under each of the possible industry structures. We begin with the unintegrated industry structure.

### 3.2 Unintegrated Industry Structure

If neither hardware firm integrates in the first stage, in the second stage hardware firms choose the price of hardware and the number of software varieties for each technology is determined by free-entry.

The profits of hardware firm A are

$$\pi_A = tp_A = \frac{[(1-\beta)(N_A^\beta - N_B^\beta) - (p_A - p_B) + 1]}{2} p_A \tag{6}$$

where we have used (5) for $t$, the market share of technology A. Maximizing the above equation with respect to $p_A$ yields the following best response function for firm A:

$$p_A = \frac{(1-\beta)(N_B^\beta - N_A^\beta) + p_B + 1}{2}. \tag{7}$$

Similarly, the best response function for firm B is

$$p_B = \frac{(1-\beta)(N_A^\beta - N_B^\beta) + p_A + 1}{2}. \tag{8}$$

The profit of a representative software firm which provides a program for hardware A is

$$\pi_A^s = \rho_A t - F. \tag{9}$$

Substituting in (5) for $t$ yields

$$\pi_A^s = \beta N_A^{\beta-1} \frac{[(1-\beta)(N_A^\beta - N_B^\beta) - (p_A - p_B) + 1]}{2} - F. \tag{10}$$

Setting (10) equal to zero implicitly defines the free-entry number of software varieties provided for hardware A. Setting the analogous equation equal to zero for technology B implicitly defines the free-entry number of software varieties provided for hardware B.

The simultaneous solution of the two hardware best response functions and the two free-entry conditions define a Nash equilibrium to this subgame. We have the following proposition.[15]

**Proposition 1** *The unique symmetric equilibrium in the unintegrated industry structure subgame is characterized by hardware price $p_A = p_B = p_U = 1$ and $N_A = N_B = N_U = (\frac{B}{2F})^{1/(1-\beta)}$ software varieties. Since each technology has half of the market (t=1/2), equilibrium hardware profits for each hardware firm are $\pi_U = 1/2$.*

*Proof.* Setting $p_A = p_B$ and $N_A = N_B$ implies that $t = 1/2$. Substituting into (7) and (8) and into the two free entry conditions yields $N_A = N_B = N_U = (\frac{B}{2F})^{1/(1-\beta)}$ and $p_A = p_B = p_U = 1$. *Q.E.D.*

### 3.3 Integrated Industry Structure

If both hardware firms integrate into software in stage one, they first choose the number of software varieties to offer and then choose prices. We begin with the third stage, in which prices are determined.

From lemma (1), hardware firm $A$ will charge $\rho_A = \beta N_A^{\beta-1}$. Revenues per software variety for firm A are $\beta N_A^{\beta-1} t$ and total software revenues are $\beta N_A^{\beta} t$. Thus, the integrated profits of hardware firm A are

$$\pi_A = t(p_A + \beta N_A^{\beta}) - N_A F. \tag{11}$$

[15]The parameter restriction $F > \beta^{(1/\beta)}/2$ ensures that the software profit functions are decreasing functions of the number of software varieties on each network in equilibrium.

Maximizing (11) with respect to $p_A$ and the analogous profit function for firm B with respect to $p_B$ yields price best response functions for firms A and B:

$$p_i = \frac{[(1-2\beta)N_i^\beta - (1-\beta)N_j^\beta + p_B + 1]}{2}, i = A, B, j \neq i. \tag{12}$$

By comparing these price best response functions with equations (7) and (8), it is clear that for given $N_A$ and $N_B$, integrated hardware prices will be lower than unintegrated hardware prices, i.e., price competition is more intense under the integrated industry structure. This is due to the internalization of a pricing externality. In the integrated setting, hardware firms have an additional incentive to lower the price of hardware: lower hardware prices lead to increased software sales and profits by increasing market share.

Using (12), the Nash equilibrium hardware prices in the second stage, contingent on $N_A$ and $N_B$ are

$$p_i = \frac{[(1-3\beta)N_i^\beta - N_j^\beta + 3]}{3}, i = A, B, j \neq i. \tag{13}$$

In the second stage, the hardware firms determine the number of software varieties supplied. Substituting (13) into (5), yields an expression for the market share of firm A as a function only of $N_A$ and $N_B$:

$$t = (N_A^\beta - N_B^\beta + 3)/6.$$

Substituting this expression and (13) into (11), the profits of firm A as a function of $N_A$ and $N_B$ can be written as

$$\pi_A = (N_A^\beta - N_B^\beta + 3)^2/18 - N_A F. \tag{14}$$

Differentiating the above expression with respect to $N_A$ yields the following first order condition:

$$\beta N_A^{\beta-1}(N_A^\beta - N_B^\beta + 3)/9 - F = 0. \tag{15}$$

From the above analysis, we can state the following proposition.[16]

**Proposition 2** *The unique symmetric equilibrium in the integrated industry structure subgame is characterized by hardware price $p_A = p_B = p_I = 1 - \beta N_I^\beta$ and $N_A = N_B = N_I = (\frac{B}{3F})^{1/(1-\beta)}$ software varieties. Since each technology has half of the market (t=1/2), equilibrium hardware profits for each hardware firm are $\pi_I = 1/2 - F(\frac{B}{3F})^{1/(1-\beta)}$.*

*Proof.* Simultaneous satisfaction of the two variety best response functions yields $N_I$. Substituting into the price best response functions yields $p_I$. Symmetry implies that t=1/2, and equilibrium profits are found by substituting into (11). *Q.E.D.*

Comparing the integrated and unintegrated industry structures, we can state the following proposition.

**Proposition 3** *Relative to the unintegrated structure, there are lower prices of hardware, fewer software varieties, and lower profits in an integrated structure.*

*Proof.* Proposition (3) follows from Propositions (1) and (2). *Q.E.D.*

Relative to the unintegrated number of software varieties there are two opposing effects which determine the number of software products provided by an integrated firm. These are the price effect and the demand effect. The internalization of the effect of hardware pricing on the market for software encourages more competitive pricing in the market for hardware for a given number of software products. This gives hardware firms an incentive to decrease the number of varieties provided relative to the

[16] We assume that equilibrium profits in the integrated industry structure are positive; it can easily be shown that these profits are positive whenever $F > 2^{(1-\beta)/\beta}(\beta/3)^{(1/\beta)}$. We verified that second order conditions hold for $\beta < 1/2$ by computational analysis of the parameter space. This analysis is available from the authors upon request. When $1/2 \leq \beta < 1$, there is no symmetric equilibrium in pure strategies. There are two asymmetric equilibria in which only one platform exists. Since we are interested in comparing integrated and unintegrated *oligopolies*, we do not analyze this case. Church and Gandal (1990) investigate the incentives for and effects of standardization.

unintegrated number. On the other hand, increasing the number of software varieties has a demand effect since it increases the consumption benefit of the technology and hence market share. Proposition (3) indicates that the pricing effect dominates and hence integrated firms provide less variety relative to the unintegrated solution. This reduction in the number of software varieties is not sufficient to keep the integrated price of hardware from falling below the unintegrated price. The equilibrium hardware price in the integrated structure equals the unintegrated price less a subsidy equal to software revenues per consumer. Consequently profits in the integrated equilibrium are less than in the unintegrated structure as hardware prices are less and the integrated firm also incurs fixed costs of software.

### 3.4 Partially Integrated Industry Structure

In this section we determine the outcome to the subgame in which only one of the hardware firms integrates in the first stage. Suppose that the integrated firm is A. In the second stage, the integrated firm will choose the number of software products to offer for its technology. In the third stage, hardware firm A and B will choose their hardware price and the number of software firms for technology B will be determined by free entry.

We begin with the third stage. The hardware price best-response function for firm A is given by (12), while that for firm B by (8). Solving these two equations yields equilibrium values for the hardware prices contingent on $N_A$ and $N_B$.

$$p_A = \frac{[(1-3\beta)N_A^\beta - N_B^\beta + 3]}{3} \tag{16}$$

$$p_B = \frac{[(1-\beta)N_B^\beta - N_A^\beta + 3]}{3}. \tag{17}$$

Substituting the above two expressions into (5), the equilibrium market share for firm

A as a function of $N_A$ and $N_B$ is

$$t = \frac{N_A^\beta - (1-\beta)N_B^\beta + 3}{6}. \tag{18}$$

An interior equilibrium requires $t < 1$, or $-N_A^\beta + (1-\beta)N_B^\beta + 3 > 0$. In an interior equilibrium, the free-entry number of software firms for technology B is determined by the zero profit condition, $\beta N_B^{\beta-1}(1-t) = F$, which can be expressed as

$$\beta N_B^{\beta-1}\frac{(-N_A^\beta + (1-\beta)N_B^\beta + 3)}{6} = F \tag{19}$$

by substituting in for $t$ from (18). Equation (19) implicitly defines the free-entry equilibrium number of software products available for firm B's technology as a function of $N_A$. We now solve the second stage for $N_A$. Substituting (16), (17), and (18) into (11), the profits of firm A can be written as

$$\pi_A = \frac{(N_A^\beta - (1-\beta)N_B^\beta + 3)^2}{18} - N_A F. \tag{20}$$

In the second stage firm A optimizes over $N_A$, taking into account the dependence of $N_B$ on its choice of $N_A$, i.e., subject to (19). Maximizing (20) with respect to $N_A$ yields the following best response function:

$$\frac{(N_A^\beta - (1-\beta)N_B^\beta + 3)}{9}\beta(N_A^{\beta-1} - (1-\beta)N_B^{\beta-1}\frac{dN_B}{dN_A}) - F = 0. \tag{21}$$

From (19), the foreclosure effect $\frac{dN_B}{dN_A}$ is

$$\frac{dN_B}{dN_A} = \frac{\beta N_B N_A^{\beta-1}}{(\beta-1)(-N_A^\beta + (1-2\beta)N_B^\beta + 3)} \tag{22}$$

Substituting (22) into (20) yields

$$\frac{(N_A^\beta - (1-\beta)N_B^\beta + 3)}{9}\beta N_A^{\beta-1}\frac{(-N_A^\beta + (1-\beta)N_B^\beta + 3)}{(-N_A^\beta + (1-2\beta)N_B^\beta + 3)} - F = 0. \tag{23}$$

We can state the following lemma.

**Lemma 2** *The foreclosure effect is negative in an interior equilibrium, i.e., when the integrated firm offers more software products, the number of software products available for the unintegrated firm's technology declines.*

*Proof.* Since the numerator of (23) will be positive in an interior equilibrium, the denominator of (23), $(-N_A^\beta + (1-2\beta)N_B^\beta + 3)$, must also be positive in an interior equilibrium. From (22), $\frac{dN_B}{dN_A} < 0$. *Q.E.D.*

Using lemma (2), we can state the following corollary.

**Corollary 1** *In an interior equilibrium, the equilibrium market share of the integrated firm exceeds* 1/2.

*Proof.* Consider the case when there is no foreclosure effect, i.e., $\frac{dN_B}{dN_A} = 0$. Suppose $t = 1/2$. This would imply that $N_A^\beta = (1-\beta)N_B^\beta$ from (18). From (21), when there is no foreclosure effect, $N_A^{(\beta-1)} = 3F/\beta$ and from (19), $N_B^{(\beta-1)} = 2F/\beta$. Thus $N_A^\beta > (1-\beta)N_B^\beta$, implying that $t > 1/2$, which is a contradiction. Therefore when there is no foreclosure effect, $t > 1/2$. Adding the foreclosure effect means that $N_A^{(\beta-1)} > 3F/\beta$ and $N_B^{(\beta-1)} < 2F/\beta$, which means that $t > 1/2$ always. *Q.E.D.*

The selection of $N_A$ by firm A in stage two is determined by the interplay of two opposing forces. On the one hand, by reducing $N_A$, firm A can reduce the degree of price competition in the second stage. On the other hand, increasing $N_A$ has both a demand and a foreclosure effect. It makes the hardware technology of firm A more attractive and it reduces $N_B$, which makes firm B's technology less attractive. When consumers place a low value on variety, the incentive to mitigate price competition will dominate, while when consumers place a high value on variety, the demand and foreclosure effect will dominate. Although analytical solutions can not be obtained in an interior equilibrium, the representative simulation shown in Figure 2 illustrates these effects.

INSERT FIGURE 2 ABOUT HERE

Figure 2 shows the ratio of $N_{PI}/N_{PU}$, where $N_{PI}$ is the equilibrium number of software varieties chosen by the integrated firm in an interior equilibrium and $N_{PU}$ is the free-entry equilibrium number of software varieties provided for the unintegrated firm. Figure 2 also shows the ratio of the equilibrium hardware prices for each firm $p_{PI}/p_{PU}$ and equilibrium profits for each firm ($\pi_{PI}$ and $\pi_{PU}$), in addition to the equilibrium market share for firm A ($t$). Figure 2 also shows the monopoly profits associated with complete foreclosure.[17]

For low values of $\beta$, the integrated firm offers fewer software varieties than the unintegrated technology in an attempt to mitigate its own pricing behavior. For the simulation shown in figure 2, whenever $\beta < .320$, the integrated firm offers less software products than are available for the unintegrated technology, i.e., $N_{PU} > N_{PI}$. The profits of the integrated firm are slightly declining in $\beta$ in this region since increases in $\beta$ make its pricing behaviour more aggressive.

For $\beta > .320$, the demand and foreclosure effects dominate and the integrated firm offers more varieties than its rival. Once it is profitable to foreclose, increases in $\beta$ make it easier to do so and hence profits increase in $\beta$ in this region.

By selecting an $N$ such that $t = 1$, firm A can completely foreclose technology B. If $t = 1$, then the extent of the software market for hardware B is zero, and no software firms will enter. Without software provision, hardware firm B has no sales and makes zero profits. The number of software firms (denoted $N^m$) which firm A must provide to completely foreclose firm B is found by setting $t = 1$ in (18), yielding $N^m = 3^{(1/\beta)}$. The profits of firm A when it is a monopolist are[18]

$$\pi^m = 2 - 3^{(1/\beta)}F. \tag{24}$$

[17] We again verified second order conditions computationally.

[18] To derive these profits, substitute $N^m = 3^{(1/\beta)}$ into (20) or substitute $t = 1$ into (1), and find the maximum hardware price such that a consumer with tastes $t = 1$ just prefers to buy a system.

Notice that when $\beta = .407$ in figure 2, the foreclosure profits earned by an integrated firm in a "monopoly" equilibrium ($\pi^m$) exceed the profits earned in an interior equilibrium. For $\beta \geq .407$, the equilibrium in this subgame will involve the integrated firm completely foreclosing the unintegrated firm.

### 3.5 Subgame Perfect Equilibrium and Incentives for Integration

We are now ready to solve the full game. The payoff matrix for the integration stage is[19]

| | | Firm B | |
|---|---|---|---|
| | | Integrated | Unintegrated |
| Firm A | Integrated | $(\pi_I, \pi_I)$ | $(\pi^*_{PI}, \pi^*_{PU})$ |
| | Unintegrated | $(\pi^*_{PU}, \pi^*_{PI})$ | $(\pi_U, \pi_U)$ |

The equilibrium profits in an unintegrated industry structure are simply 1/2, which is independent of the value that consumers place on variety. Since monopoly profits ($\pi^m$) are increasing in the value that consumers place on variety ($\beta$), then for any value of F, the incentive for complete foreclosure is increasing in $\beta$. The preceding discussion is summarized by the following proposition.

**Proposition 4** *When monopoly profits are greater than the equilibrium profits earned in an unintegrated industry structure, the equilibrium industry structure will be integrated, i.e., whenever $F < 3^{(\beta-1)/\beta}/2$, the unique subgame perfect equilibrium is for both firms to integrate and offer $N_I$ varieties and charge price $p_I$.*

*Proof.* Monopoly profits are greater than the profits earned in an unintegrated industry

[19] $\pi^*_{PI}$ now refers to the equilibrium profits in the partially integrated structure for the integrated firm and is the maximum of profits earned in an interior equilibrium and profits earned in a "monopoly" equilibrium. Similarly $\pi^*_{PU}$ refers to the equilibrium profits of the unintegrated firm in the partially integrated industry structure. If the integrated firm completely forecloses, these profits are equal to zero.

structure whenever $\pi^m > 1/2$ or, rearranging terms, whenever $F < 3^{(\beta-1)/\beta}/2$. Thus integrating is a best response to not integrating whenever $F < 3^{(\beta-1)/\beta}/2$. Since we assumed that equilibrium profits are positive in the integrated structure, integration is the best response to "disintegration." Thus whenever $F < 3^{(\beta-1)/\beta}/2$, it is a dominant strategy to integrate in the first stage. The unique subgame perfect equilibrium is for both firms to integrate and offer $N_I$ varieties and charge price $p_I$.[20] *Q.E.D.*

Figure 3 shows the equilibrium structure as a function of $\beta$ and F.[21] For fixed values of F, if $\beta$ is relatively small (Region A, figure 3), the unique subgame equilibrium is for both hardware firms to remain unintegrated and charge price $p_U$. If $\beta$ is relatively large (Regions C1 and C2), the unique subgame perfect equilibrium is for both firms to integrate and charge price $p_I$ and offer $N_I$ varieties. In region C1, proposition (4) holds. In region (C2), monopoly profits in the partially integrated structure are less than the equilibrium profits earned in the unintegrated industry structure, but $\pi_{PI}$, the profits earned in the interior equilibrium in the partially integrated structure exceed the equilibrium profits earned in the unintegrated industry structure. In this region, the integrated firm partially forecloses on its unintegrated rival. If $\beta$ falls in an intermediate range (Region B), there are two subgame perfect equilibria: (1) both firms remain unintegrated and charge $p_U$ and (2) both firms integrate and charge price $p_I$ and offer $N_I$ software varieties. However, the unintegrated industry equilibrium Pareto dominates the integrated industry equilibrium.

INSERT FIGURE 3 ABOUT HERE

[20]Recall that (1) equilibrium profits in the integrated structure are positive whenever $F > 2^{(1-\beta)/\beta}(\beta/3)^{(1/\beta)}$ and that (2) software profit functions are decreasing in N in the unintegrated structure whenever $F > \beta^{(1/\beta)}/2$. Since $max[2^{(1-\beta)/\beta}(\beta/3)^{(1/\beta)}, \beta^{(1/\beta)}/2] < 3^{(\beta-1)/\beta}/2$ for all $0 < \beta < 1/2$, there exists a range on F for all $\beta$ such it is a dominant strategy to integrate in the first stage. In what follows, we assume that $F > .085$. This insures that both restrictions hold for all $0 < \beta < 1/2$.

[21]Although the boundary between Regions A and B and the boundary between Regions B and C2 were generated by simulation, figure 3 is equivalent to an analytical solution, because it shows the equilibrium for all values of the parameter space ($\beta$, F).

Proposition (4) and Figure 3 show that the game has the structure of a prisoners' dilemma when consumers place a high value on an additional variety of software. The equilibrium industry structure is integrated, even though both hardware firms would prefer an unintegrated structure. However, if the other hardware firm is unintegrated, each firm has an incentive to integrate and strategically provide enough varieties of software to foreclose software access for their rival and become a monopolist. The defensive response of the unintegrated rival firm is to also integrate.

# 4. Welfare

The analysis of the preceding section suggests that the two equilibrium structures are integrated and unintegrated. In this section, we address the welfare implications of the equilibrium structures. We begin by comparing the surplus of consumers under the two equilibrium structures.

## 4.1 Consumer Surplus

In both equilibrium industry structures, the equilibrium market share for each technology is one-half. Equation (4) is the indirect utility or welfare of a consumer located distance t from the hardware firm. Substituting the equilibrium software price into (4), consumer surplus is

$$CS = 2\int_0^{1/2} [(1-\beta)N^\beta + y - p - t]dt \tag{25}$$

After making the relevant substitutions from proposition (1) for the equilibrium hardware price and number of software products, consumer surplus under the unintegrated industry structure is

$$CS_U = (1-\beta)(\frac{\beta}{2F})^{\beta/(1-\beta)} + y - 5/4 \tag{26}$$

Substituting in for the equilibrium hardware price and number of software firms from proposition (2), consumer surplus under the integrated industry structure is

$$CS_I = (\frac{\beta}{3F})^{\beta/(1-\beta)} + y - 5/4. \tag{27}$$

The preceding analysis leads to the following proposition.

**Proposition 5** *Consumer surplus is always higher under the integrated structure than under the unintegrated structure.*

*Proof.* Compare (27) and (26). *Q.E.D.*

The intuition for this result is that the lower equilibrium hardware price under integration more than compensates for the lower equilibrium number of software products.

### 4.2 Total Surplus

The total surplus in each of the two industry structures is simply the sum of industry profits and the surplus of each consumer. For the unintegrated structure, the free-entry equilibrium for the software industry results in zero aggregate profits for the software industry. The total surplus if the industry is unintegrated is

$$TS_U = CS_U + \pi_U = (1-\beta)(\frac{\beta}{2F})^{\beta/(1-\beta)} + y - 1/4, \tag{28}$$

while the total surplus for the integrated industry structure is

$$TS_I = CS_I + \pi_I = (\frac{\beta}{3F})^{\beta/(1-\beta)} + y - 2F(\frac{\beta}{3F})^{1/(1-\beta)} - 1/4. \tag{29}$$

Comparing the total surplus under the two structures, we can state the following proposition.

**Proposition 6** *The total surplus associated with the unintegrated industry structure always exceeds that of the integrated structure.*

*Proof.* Compare (29) and (28). *Q.E.D.*

The higher consumer surplus under the integrated industry is not sufficient to compensate for the profit differential. If the parameters are such that proposition (4) holds, the equilibrium industry structure is integrated, even though total surplus would be greater under an unintegrated industry structure. On the other hand, in these circumstances consumers are better off.

## 5. Conclusion

Our analysis suggests that integration by hardware producers into the provision of software is more likely to occur when consumers place a relatively high value on variety. In the electronics & entertainment industry, casual empiricism suggests that the value of variety is relatively high. In the computer industry, on the other hand, some minimal amount of variety is important, but there are rapidly diminishing returns to additional variety compared to the entertainment industry. We would therefore expect integration in the electronics industry and not in the computer industry. Moreover, we would expect that once one electronics manufacturer integrated into software, its rival hardware manufacturers would be forced to do the same to avoid being foreclosed from software.

Finally, we assumed that integration meant that a hardware firm was the exclusive supplier of software for its technology. An alternative assumption is that even in the integrated case, a free-entry equilibrium in the provision of software is required. We now discuss the implications of this alternative assumption.

When integration precludes independent software provision, there are two opposing effects which determine the number of software products an integrated hardware firm provides: the pricing effect and the demand effect. The dominance of the pricing effect resulted in a hardware firm providing less software than in the free-entry equilibrium.

These same two factors will also determine the number of software products supplied by an integrated hardware firm when independent software provision is not precluded. The demand effect still provides the integrated firm with an incentive to supply some software varieties, despite the invariance of the *equilibrium* number of software varieties to the number of varieties supplied by the integrated firm.

The reason is that the two sources of software have a differential effect on the market share of the hardware firm. This is because the provision of software by the hardware firm commits the hardware firm to price more aggressively. Hence even if there was a one-for-one displacement, expansion of the number of software varieties by the hardware firm would still result in an increase in market share. Moreover, because there is an increase in market share, there will not be one-for-one displacement. Rather there will be a net increase in the total varieties supplied, increasing the attractiveness of the hardware technology. This is the demand effect.

The total number of software varieties provided in equilibrium under either the integrated structure or the unintegrated structure will be the same, since in both cases the equilibrium market share of each technology is one half. Since the hardware firms will provide some software in equilibrium, equilibrium hardware profits will still be lower in the integrated subgame than in the unintegrated subgame. Moreover when consumers place a high variety on software, the unique subgame perfect equilibrium will still be for both hardware firms to integrate. In these circumstances the demand and foreclosure effects still give a hardware firm an incentive to integrate when its rival is not integrated; hence the game will still have the structure of a prisoners' dilemma. Consumers will still prefer the integrated structure, since equilibrium hardware prices will still be lower in the integrated industry structure and the equilibrium number of software products will be the same under each structure. Thus our results are robust to the assumption that integration does not preclude independent software provision.

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Figure 1: Timing of the Game

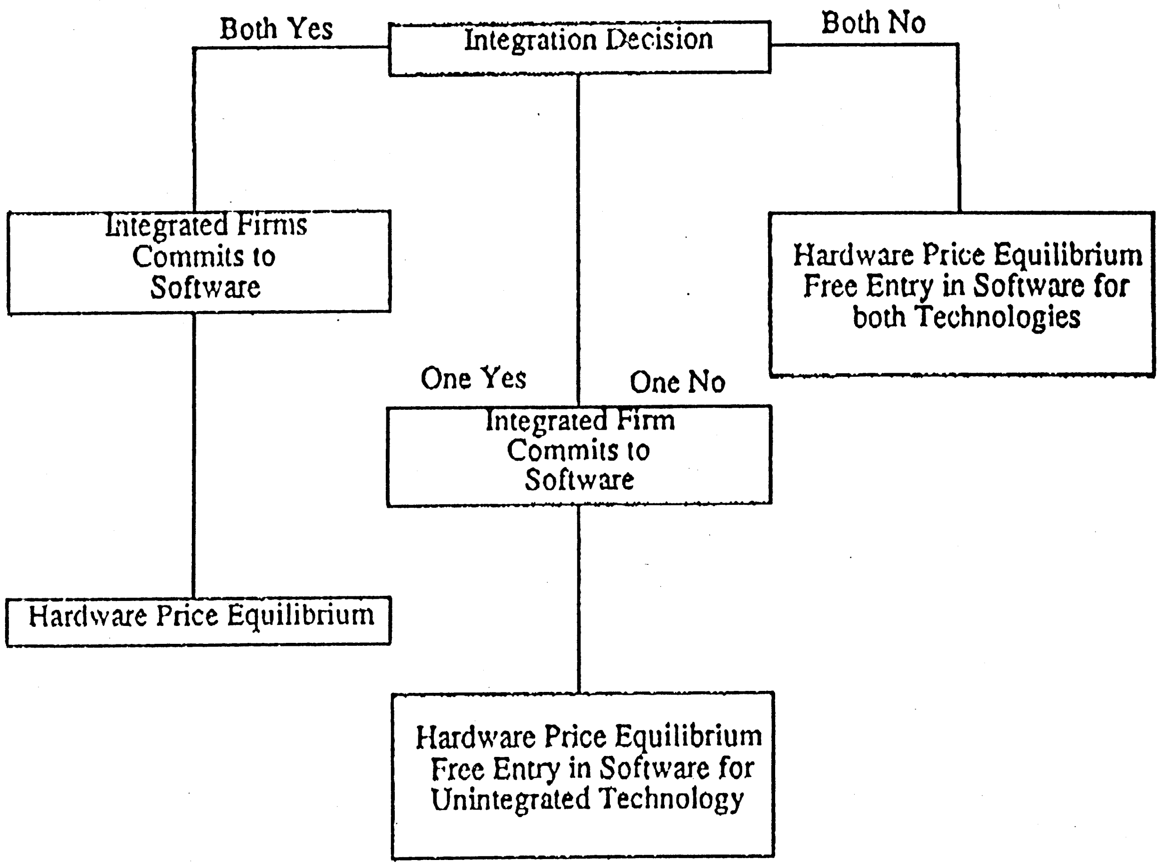

Figure 2 Partially Integrated Structure

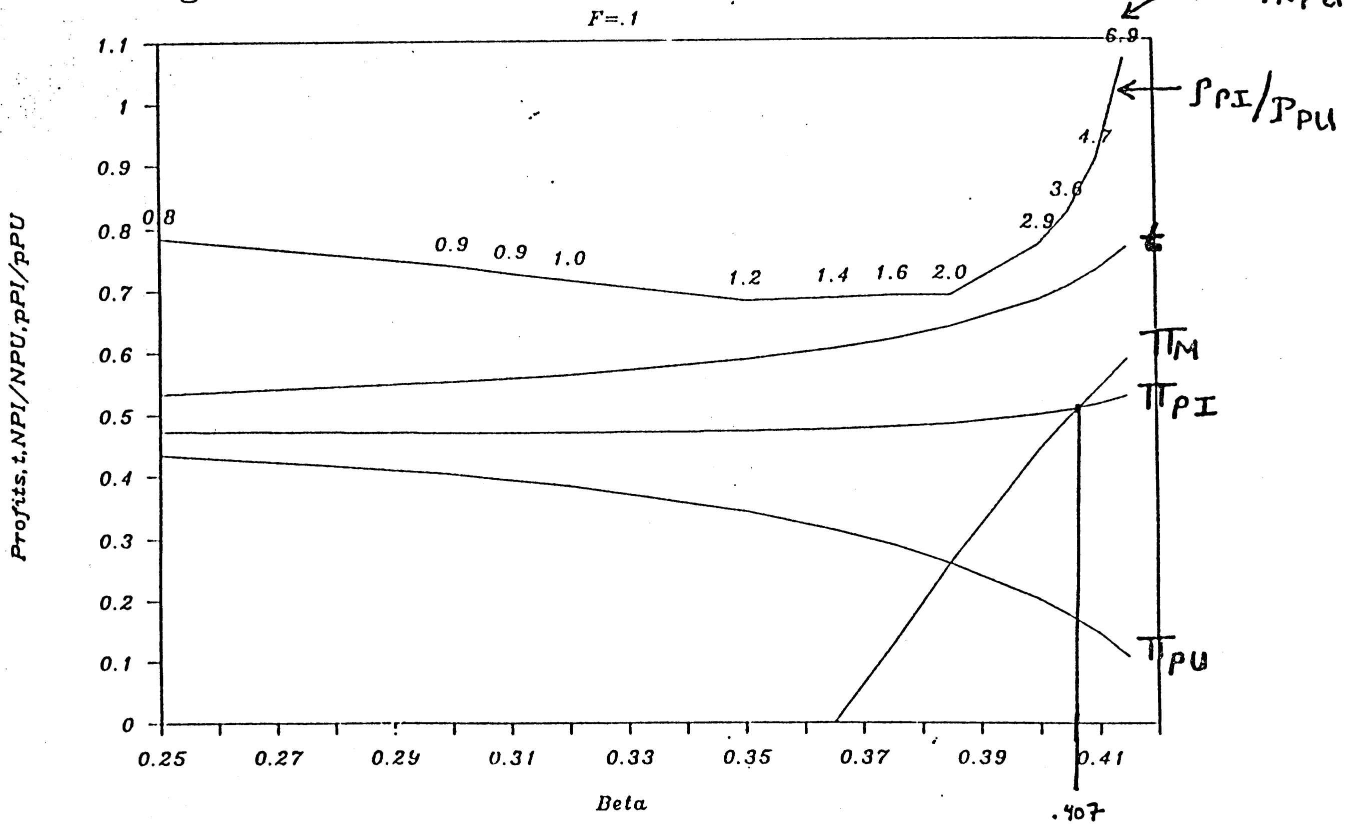


Figure 3 Equilibrium Industry Structure