LICENSING AND THE BATTLE BETWEEN STANDARDS

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This paper considers the competition between rival incompatible systems composed of hardware and complementary software, and models a strategy commonly used by developers of hardware standards, the licensing of technology to third-party firms. Licensing acts as a commitment to lower hardware prices, which increases the willingness of software developers to sink money into development of software for the licensed technology. The resulting increased software availability in turn increases hardware adoption. Results show that licensing is profitable when software development costs are relatively low and when only one firm licenses. Hence there exists a coordination game, the result of which is a mixed-strategy licensing equilibrium, where consumer surplus and total welfare increases, while total profits fall.

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1. Introduction:

Battles between different standards for the same type of consumer electronics product have become commonplace in today's world. A classic example is the 1970's battle between Sony's Betamax and JVC's VHS video-cassette recorder standards. Both products provided the same basic service, though minor differences did exist: the Betamax picture was acknowledged to be better and the VHS recording time was initially longer. Though Sony had a first-mover advantage and a corresponding lead in the market for several years, the VHS standard eventually won. Examination of the strategies adopted by Sony and JVC indicates one major point of divergence: JVC was much more liberal than Sony in its licensing arrangements. This paper explains how widespread licensing can affect the outcome of a battle between standards by tipping the balance in favor of the licensor, both in terms of acceptance of the product and increased profits.

All products concerned in these battles are in fact constituents of systems, usually composed of two main parts: a hardware component and complementary products, such as software and/or peripherals. Of particular interest about these systems is that the hardware component is useless without compatible software. Furthermore, the greater the variety of software, the greater the utility derived from the system; hence software availability is a critical factor for consumers who have to choose among various system standards. As a result, stimulating the development of software becomes a major strategy objective for hardware vendors and the issue becomes: how can hardware vendors influence software development?

Software firms may be reticent to invest in the development of software for new, unproved hardware products since development of software entails a fixed cost which is in part hardware-specific, and therefore sunk. This reticence is especially pronounced in cases where two different standards are both new and in competition. In such cases prospective software firms may prefer to adopt a wait-and-see approach, and develop software only once one of the hardware products has gained favor in the market. This leads to a type of chicken-and-egg problem: if little distinguishes two or more system standards *ex ante* then software firms may wait to see which standard is preferred by consumers, while consumers are likewise waiting before purchasing to see which standard is supported by third-party software developers.

To deal with the chicken-and-egg problem, licensing acts as a signal to the software firms that the licensed hardware product will gain acceptance in the market. The reason for this is that licensing is a credible commitment to lower hardware prices by creating competition. These lower prices translate to greater expected hardware sales and, with this expectation, more software firms are induced to sink costs and enter the market for the licensed hardware, which in turn further increases hardware sales. This positive indirect network effect on hardware sales can offset the price decrease from licensing, thereby increasing the total profits of the licensor.

Evidence from major battles of standards support the hypothesis of this paper. Reference is made for example to the Sony vs. JVC battle mentioned above, but also to the computer operating systems battle between Apple and Microsoft. In the latter case, Apple Computer began licensing its proprietary operating system in an attempt to increase first software availability and then hardware market share.[2] In addition, the lessons of the Betamax-VHS battle were not lost on its participants. In a re-run of this battle, two standards were developed for the video compact disk. Both sides, Sony and Philips on the one hand and Toshiba on the other, are currently trying to sign up licensees in advance to back their standard.[3]

This paper is closely related to papers by Economides (1995) and Kende (1995). In both of these papers a monopolist licenses a hardware standard in order to profit from network externalities. In Economides (1995) the network externalities are direct. If the network effect is strong enough the monopolist can increase profits by inviting entry. In Kende (1995) the network externalities are indirect, arising through the demand for compatible software. As in

[2] *Business Week* states that: "[Apple] executives say the company needs to boost the share of computers that use Apple software to 20% of the PC market to keep software developers interested in writing programs for Macintosh over the long haul. With only 10% of the PC market now, Apple is unlikely to reach its goal without the help of clonemakers ." "Anybody Wanna Clone a Mac?," *Business Week*, September 26, 1994.

[3] To complete the re-run, Matsushita, a key backer of the VHS standard, has chosen to back Sony's competitor yet again. A key difference in this battle is the role of "software" firms, namely movie studios and other video providers. Since the Betamax-VHS battle backers of both standards have themselves integrated into movie studios (Sony-Columbia and Matsushita-MCA). In addition, this time both sides are seeking the early endorsement of independent video companies such as Time Warner.

the present paper, licensing acts as a commitment to lower prices on hardware, inducing more software developers to support the particular standard. The results show that licensing is a profitable strategy even when it is not a strategic move intended to affect the outcome of a battle among standards.

The model used in this paper draws on that of Church and Gandal (1993a). In both models there are two differentiated hardware standards and a variety of software for each standard. Church and Gandal use the model to show the incentives of a hardware firm to vertically integrate into software production. Church and Gandal (1993b) show the case where the vertically integrated system supplier no longer makes software compatible with the rival system. This can lead to monopolization of the hardware market. In the present paper there is no vertical integration by either hardware firm.

This paper is also related to the second-sourcing literature (see Farrell and Gallini, 1988, and Shepard, 1987). In this literature consumers must incur a setup or adoption cost before price or quality is chosen by a monopolist. If the seller cannot contract on price or quality *ex ante* there is a dynamic consistency problem; *ex post* the firm would choose a relatively high price or low quality level. Second-sourcing may increase profits by ensuring *ex post* competition leading to lower prices or higher quality levels. Here licensing is a commitment to a low future price level for hardware, which induces firms to incur the sunk cost of developing software for the licensed standard. As in the second-sourcing literature, creating competition can increase profits. The difference with the second-sourcing literature is that in this paper licensing is a strategic move to affect the competition between two rival firms.

This paper's model is presented in the next Section. Results are derived for the following situations: (i) neither competing standard is licensed; (ii) only one of the standards is licensed; and finally (iii) both standards are licensed. Welfare comparisons among these three equilibria are presented in Section 3. Comparison of the profits to be earned in the three equilibria suggests a coordination game: both firms would prefer to be the sole licensee, but prefer no licensing at all to the case where both firms license. This licensing equilibrium is explored in Section 4. Finally, the conclusion is presented in Section 5.

2. Model

This model follows the one used in Church and Gandal (1993a). Consumers derive utility from consumption of a system consisting of hardware and a variety of software. Consumers have unit demands for hardware and each variety of software. There are two incompatible systems, *A* and *B*. Consumers' tastes for these systems are distributed uniformly along a line of length one, with the systems at either end of the line. Consumers utility for product *i* is:

$$U_i = N_i^{\frac{1}{2}} + \alpha + x - \upsilon_i. \tag{1}$$

where N_i is the amount of software consumed. Utility increases in the variety of software consumed, but at a decreasing rate. Consumers receive a standalone benefit of α from the system, where α is large enough so that in equilibrium the market is covered, and incur a cost of ν_i to "travel" to system *i*. Finally, *x* represents consumption of an outside good. The budget constraint is:

$$y = \sum_{j=1}^{N_i} \rho_j + p_i + x$$

where the price of the hardware unit is p_i, and total expenditure on software equals $\sum_{j=1}^{N} \rho_j$.

For simplicity I assume that software is symmetric; therefore expenditures on software equal $N_i \rho_i$. From the maximization of net utility one can show that the equilibrium software price is:

$$\rho_i = \frac{1}{2} N_i^{-\frac{1}{2}}. \tag{2}$$

No software vendors have any incentive to deviate from this price. There is no incentive to lower price; because of the unit demand for software, sales would not increase and profits would fall. Likewise, there is no incentive to raise price, because a higher price is greater than the marginal utility of the software to the consumer so sales and profits would fall to zero. By substituting, indirect utility can be shown to be:

$$V_i = \frac{1}{2} N_i^{\frac{1}{2}} + y + \alpha - \upsilon_i - p_i. \tag{3}$$

Consumers buy *A* as long as $V_A > V_B$. The demand for system *A* comes from all consumers to the left of the consumer indifferent between systems *A* and *B*, ν, defined to be:

$$\upsilon = \frac{.5(N_A^{\frac{1}{2}} - N_B^{\frac{1}{2}}) - (P_A - P_B) + 1}{2}. \tag{4}$$

Demand for system *B* is 1-ν.

The timing of the game is as follows. In the first stage the systems are announced by firms *A* and *B*. If either or both firms are planning to license this is also announced at this stage, along with all parameters of the licensing agreements. In the second stage software firms choose a hardware standard to support and sink *F* in developing a variety of software for that standard. It is assumed that there is monopolistic competition in software, with free entry until profits equal zero. Finally, in the third stage firms set prices and there are sales of both hardware and software.

The profits of the hardware firms are:

$$\pi_A = p_A \upsilon \tag{5}$$

and

$$\pi_B = p_B (1 - \upsilon). \tag{6}$$

It is assumed that the hardware firms have no costs. The software firms face a fixed cost, *F*, to develop a variety of software for one of the hardware types. I assume throughout that $F > 1/8$, so that all equilibria exist. The profits of the firms providing software for each of the respective systems are:

$$\pi_A^s = \rho_A \upsilon - F \tag{7}$$

and

$$\pi_B^s = \rho_B (1-\upsilon) - F. \tag{8}$$

2.1 No licensing.

The first game examined is the benchmark case where neither firm licenses. The timing is as follows. In stage one, the systems are announced by the hardware producers. In stage two, software developers sink F to develop products for either of the systems. Finally, in stage three, the hardware producers set prices given the amount of software available. The game is solved backwards to ensure subgame perfection.

In stage three, the hardware producers maximize profits (5) and (6) respectively, given the amount of software which was developed in stage two. From the first-order conditions the reaction functions are:

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

and

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

Solving the reaction functions for hardware prices yields:

$$p_A = \frac{1}{6}(N_A^{\frac{1}{2}} - N_B^{\frac{1}{2}}) + 1 \tag{9}$$

and

$$p_B = \frac{1}{6}(N_B^{\frac{1}{2}} - N_A^{\frac{1}{2}}) + 1. \tag{10}$$

In stage two software developers enter until profits (7) and (8) equal zero. In stage one both systems are introduced. The following proposition holds:

Proposition 1[4]

In equilibrium the market is divided evenly between systems A and B, i.e. $v=1/2$. The hardware prices are:

$$p_A = p_B = 1 \ ,$$

and the variety of software available is:

$$N_A = N_B = \frac{1}{16F^2}.$$

Finally, profits equal:

$$\pi_A = \pi_B = \frac{1}{2}.$$

Proof:

Given the symmetry of the problem, $p_A = p_B$ and $N_A = N_B$. Therefore by substitution $v=1/2$ and $p_A = p_B = 1$. Setting software profits equal zero yields $N_A = N_B = \frac{1}{16F^2}$.

2.2 Unilateral Licensing:

In this section the equilibrium is derived where one of the two hardware firms chooses to license its system to at least one other firm. In the exposition below A is depicted to be the licensor. The results are similar if B were the sole licensor. Two related assumptions are made here: first of all, it is assumed that the products of the licensor and licensee(s) are undifferentiated; and second of all, it is assumed that if the licensor and licensee(s) charge the same price they split the market equally. In the first stage of this game firm A announces its licensing arrangement and sets the royalty r. It is shown below that licensing in this fashion constrains the future actions of the licensor.

[4] The results of this proposition are identical with those of Proposition 1 in Church and Gandal (1993a).

Lemma 1:

If the licensor, i, charges a royalty of $r<1$ to the licensee(s) this is a credible commitment to a final hardware price of $p_i = r$.

Proof:

The licensor and the licensee(s) sell undifferentiated goods. Neither has an incentive to raise the price above $p_i = r$ because they would lose all sales to the other firm. The licensee(s) won't set a price below r because this would entail charging a price below cost, causing losses. It is shown below that when the royalty is less than the price without licensing, namely $r<1$, the monopolist has no incentive set price below the royalty because *ex post* profits *increase* in price.

Thus, the first-stage licensing arrangement acts as a credible commitment that in stage three $p_A = r$. In stage two software firms enter the market for system A or B until profits equal zero. Finally, in stage three firm B sets price and there are sales of hardware and software.

Solving backwards, in stage three firm B maximizes profits taking the varieties of software and the price of hardware A as given. Solving the first-order condition gives:

$$p_B^{LA} = \frac{\frac{1}{2}(N_B^{LA^{\frac{1}{2}}} - N_A^{LA^{\frac{1}{2}}}) + p_A^{\frac{1}{2}} + 1}{2} \tag{11}$$

where the LA superscript refers to the case where firm A licenses. In stage two there is free entry of software firms until profits equal zero. Software firms consider both the expected price of hardware B given in equation (11) and the fact that the price of the licensed hardware will equal the royalty when making their entry decisions. By setting the profit functions (7) and (8) equal to zero one can solve for the variety of software available for the respective systems:

$$N_A^{LA} = \left(\frac{12F - 4Fp_A^{LA} - 1}{4F(8F-1)}\right)^2 \tag{12}$$

and

$$N_B^{LA} = \left(\frac{4F + 4Fp_A^{LA} - 1}{4F(8F-1)} \right)^2 . \tag{13}$$

Substituting these values into the expression for ν given in equation (4) gives:

$$\upsilon^{LA} = \frac{12F - 4Fp_A^{LA} - 1}{2(8F-1)} . \tag{14}$$

This is the demand for product A, which decreases in p_A^{LA}.

In stage one the licensing firm sets the royalty rate to maximize profits. When setting the optimal royalty the monopolist accounts for the result of lemma 1, that the final hardware price will equal the royalty. The profit of firm A is $\pi_A^{LA} = p_A^{LA} \upsilon^{LA}$. This equals all revenues derived from sales of product A, because firm A receives p_A^{LA} for each of her own sales and a royalty which equals p_A^{LA} from each sale by a licensee. The monopolist maximizes these profits in p_A^{LA}. The following proposition is derived:

Proposition 2:

The price of hardware for firm A is:

$$p_A^{LA} = \frac{12F-1}{8F},$$

and for firm B the hardware price equals:

$$p_B^{LA} = \frac{20F-3}{2(8F-1)} .$$

The quantity of hardware sold by firm A is:

$$\upsilon^{LA} = \frac{12F-1}{4(8F-1)}$$

and demand for hardware B is:

$$1 - \upsilon^{LA} = \frac{20F-3}{4(8F-1)} .$$

Therefore, profits for firm A are

$$\pi_A^{LA} = \frac{(12F-1)^2}{32F(8F-1)}$$

and likewise profits for firm B are:

$$\pi_B^{LA} = \frac{(20F-3)^2}{8(8F-1)^2}.$$

Finally, the amount of software produced for system A is:

$$N_A^{LA} = \left(\frac{12F-1}{8F(8F-1)}\right)^2$$

and for system B is:

$$N_B^{LA} = \left(\frac{20F-3}{8F(8F-1)}\right)^2.$$

For $F<1/4$ licensing increases the profits of the licensor at the expense of the non-licensing rival. Total profits decrease as a result of licensing.

Proof:

The profits of firm A are maximized in p_A^{LA}. By solving the first-order condition for firm A one can derive the price of hardware A. Substituting this into equations (12) and (13) yields the varieties N_A^{LA} and N_B^{LA}. Finally, these values can be substituted into (11) to give p_B^{LA}. By comparing profits one can show that $\pi_B^{LA} < \pi_i < \pi_A^{LA}$ and $\pi_A^{LA} + \pi_B^{LA} < 2\pi_i$ for all $F<1/4$.

For low software development costs licensing is a profitable strategy for the licensor. Licensing involves a commitment by firm A to a lower future hardware price, convincing prospective software vendors that sales of hardware are going to be greater. This increases the number of vendors who are willing to provide software for system A, which has a positive indirect network effect on sales of hardware A. When $F<1/4$, the network effect on sales, added to the price effect caused by the low hardware price, increase sales to the point that overall profits of the licensor rise. The increase in software availability and sales of hardware A come at the expense of firm B. This causes firm B's profits to fall.

For relatively high software development costs licensing is not a profitable strategy. When $F>1/4$, if firm A were to charge the profit-maximizing royalty given in proposition 2, this royalty would be greater than the price would be without licensing. If software developers and firm B accepted this royalty as a price commitment, it would subsequently be more profitable for firm A to lower price in stage three below r. The presence of the licensee would not deter firm A from doing this, so licensing at royalty r in stage one does not constitute a credible price commitment on the part of firm A. Potential licensees would be unwilling to sign an agreement with the licensor because they know that they will subsequently be undercut by the licensor, and therefore, when $F > 1/4$, licensing according to proposition 2 is not a feasible strategy for either hardware firm. If the licensor sets the royalty *below* the price without licensing, while this is a credible future price commitment, it is not profitable because given the high software development costs the resulting increase in software availability is too small to make this strategy profitable. Therefore, for high software development costs licensing can not be used to increase profits.

Licensing at a low royalty acts as a credible commitment to lower the future price of hardware when software development costs are low. This commitment increases the profits of the licensor at the expense of the rival hardware firm. The reason is that the lower hardware price induces more software firms to create software for the licensed standard, which in turn increases hardware sales. When software development costs are low the increase in software availability is relatively large, and the resulting indirect network effect on sales increases profits. If software development costs are low enough, the positive effect of licensing on hardware sales can be large enough to foreclose the rival system. This case is explored in the next section.

2.2.1 Monopolization equilibrium:

When software development costs are low enough it is possible for the licensor to foreclose its rival from the market. Licensing, as shown above, increases the availability of software for the licensed standard. At the same time, software availability for the non-licensed standard falls. The lower is F, the greater the relative effect of licensing on software availability and sales of both systems. At the extreme, no software is produced for the non-licensed system. Therefore, the licensor effectively forecloses the rival system and becomes a monopolist.

Proposition 3:

For $F \leq .15$ firm A can foreclose firm B by committing via licensing to a price of:

$$p_A^m = \frac{1-4F}{4F}.$$

In this case v=1 and profits are:

$$\pi_A^m = \frac{1-4F}{4F}.$$

The number of software varieties provided for standard A is:

$$N_A^m = \frac{1}{4F^2}.$$

The profits of firm A increase in the foreclosure equilibrium while total profits fall.

Proof:

In stage one firm A sets the royalty rate, r. In stage two, entry of software firms takes place given the expected price of the licensed hardware, which, according to lemma 1, equals the royalty rate. From equation (13) one can see that if A commits to $p_A^m = \frac{1-4F}{4F}$, then $N_B^{LA} = 0$. Thus, system B is effectively foreclosed. When $F \leq .15$ it is more profitable to charge p_A^m than p_A^{LA}.

When software development costs are low enough, the effect of licensing is to foreclose the other firm. The lower the software development costs the greater the increase in software availability caused by licensing. The increased software availability multiplies the price effect of licensing on hardware demand. The increased hardware demand for the licensed system is at the expense of the rival firm, which as a result receives less software support. For low enough software development costs the result is that no software is developed for the non-licensed standard, whose sales then equal zero.

This analysis assumes that only one firm, A, licenses its product. It was shown that for $F<1/4$ licensing increases the profits of the licensor at the expense of the rival hardware firm. Therefore, both firms have an incentive to be the sole licensor, the result of which may be that both firms license their hardware simultaneously. This outcome is studied in the next section.

2.3 Bilateral Licensing:

This section analyzes the results of both firms licensing their hardware simultaneously. The timing is as follows. In the first stage both firms A and B announce that they have licensed their respective hardware standards to one or more third-party firms and simultaneously announce their respective royalties, r_A and r_B. As above this constrains the final price of hardware to be equivalent to the royalty. In stage two, software firms enter the market. Finally, in stage three, both software and hardware is sold to consumers.

The game is solved backwards. In stage three, because of a logic similar to that of lemma 1 the prices of hardware will be $p_A^b = r_A$ and $p_B^b = r_B$, where the b superscript denotes the equilibrium where both firms have licensed. In stage two there is free entry of software producers for both systems until profits equal zero. The software producers take the expected prices of hardware as given from the first-stage announcements of the hardware producers. Solving each free-entry condition (7) and (8) for the respective quantities of software yields:

$$N_A^b = \left(\frac{1 + 4F(p_A^b - p_B^b - 1)}{4F(1-4F)} \right)^2 \tag{14}$$

and

$$N_B^b = \left(\frac{1 + 4F(p_B^b - p_A^b - 1)}{4F(1-4F)} \right)^2 . \tag{15}$$

In stage one, each hardware producer sets the royalty rate charged to her respective licensees At this stage, the licensors know that as long as this royalty is below the price without licensing the final price of hardware will equal this royalty.[5] Therefore, the licensors maximize profits in the price of hardware, taking into account the effect of the hardware price on the quantities of software produced. The reaction functions of the firms are as follows:

$$p_A^b = \frac{4Fp_B^b + 4F - 1}{8F} \tag{16}$$

[5] The logic behind this statement is similar to that of lemma 1.

and

$$p_B^b = \frac{4Fp_A^b + 4F - 1}{8F}. \tag{17}$$

Solving these reaction functions for prices gives the following proposition:

Proposition 4:

For $F \leq 1/4$, if both firms license, the prices of hardware are:

$$p_A^b = p_B^b = 0,$$ [6]

and profits are:

$$\pi_A^b = \pi_B^b = 0.$$

With symmetry each system is sold to half the market, $v^b=1/2$. The quantities of software produced are:

$$N_A^b = N_B^b = \frac{1}{16F^2}.$$

Proof:

Hardware prices are derived from the two reaction functions (16) and (17). Substituting these prices into the above expressions (14) and (15) for software quantities gives N_A^b and N_B^b. The symmetry of the problem leads to an even split of the market, i.e. $v^b=1/2$.

When both firms license their respective hardware technologies, profits fall to zero. Licensing increases price competition in hardware as the firms simultaneously attempt to attract more compatible software for their systems. The price competition when both firms license intensifies the smaller is F because of the exponential increase in software availability caused by lower hardware prices. For $F \leq 1/4$ the price of hardware for both firms goes to zero. The competition in this case is so intense that there are no profits for the hardware firms. Note that due to the symmetry of the problem the market is evenly split between the two systems. Therefore, the amount of software available for each system is the same as it would be with no

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[6] In fact, the prices are

$$p_A^b = p_B^b = \frac{4F-1}{4F},$$

but for $F<1/4$ these prices are negative. Therefore, assuming non-negative prices, prices are equal to zero.

licensing. The only effect of licensing is a transfer from producers to consumers, who no longer pay for hardware.

3. Welfare Results

In this section, the measure of consumer surplus is derived and the three equilibria given above are compared on welfare grounds.

In general, consumer surplus derived from products A and B respectively is the following:

$$\begin{aligned} CS_A &= \int_0^{\upsilon}[\frac{1}{2}N_A^{\frac{1}{2}} + \alpha + y - n - p_A]dn \\ &= \frac{1}{2}N_A^{\frac{1}{2}}\upsilon + \alpha\upsilon + y\upsilon - \frac{\upsilon^2}{2} - p_A\upsilon \end{aligned} \tag{18}$$

and

$$\begin{aligned} CS_B &= \int_{\upsilon}^{1}[\frac{1}{2}N_B^{\frac{1}{2}} + \alpha + y - (1-n) - p_B]dn \\ &= \frac{1}{2}N_B^{\frac{1}{2}}(1-\upsilon) + (\alpha-1)(1-\upsilon) + y(1-\upsilon) + \frac{1-\upsilon^2}{2} - p_B(1-\upsilon) \end{aligned} \tag{19}$$

Consumer surplus in the benchmark case where neither firm licenses is:

$$CS_A = CS_B = \frac{1}{16F} + \frac{\alpha}{2} + \frac{y}{2} - \frac{5}{8}.$$

Consumer surplus for consumers of system A in the case where only A licenses is:

$$CS_A^{LA} = \frac{(12F-1)[(12F-1)(3-18F) + 16F(\alpha+y)(8F-1)]}{64F(8F-1)^2},$$

and for system B consumers' surplus is:

$$CS_B^{LA} = \frac{(20F-3)(8F-1)[16F(\alpha+y-1) - (20F-3)]}{64F(8F-1)^2} + \frac{1}{2} - \frac{1}{32}\left(\frac{12F-1}{8F-1}\right)^2.$$

When $F \leq .15$ there is monopolization by the licensor. If the licensor is firm A, the consumer surplus derived by all consumers from system A is:

$$CS_A^m = \alpha + y + \frac{1}{2}.$$

In the case where there is bilateral licensing, consumer surplus from either system is:

$$CS_A^b = CS_B^b = \frac{1}{16F} + \frac{\alpha}{2} + \frac{y}{2} - \frac{1}{8}.$$

Let welfare equal profits plus consumer surplus. A comparison of profits, consumer surplus, and welfare among the different equilibria yields the following proposition:

Proposition 5:

For the case when $.15 < F < .25$, in other words when unilateral licensing does not lead to monopolization, the following comparisons can be made:

i. Individual firm profits: $\pi_i^b < \pi_B^{LA} < \pi_i < \pi_A^{LA}$

ii. Total profits: $\pi^b < \pi^L < \pi$

iii. Consumer Surplus: $CS < CS^L < CS^b$

iv. Welfare: $W^b = W < W^L$.

For the case of $F \leq .15$ where there is monopolization under unilateral licensing, the welfare comparisons are as follows:

i. Individual firm profits: $\pi_i^b = \pi_B^m < \pi_i < \pi_A^m$

ii. Total profits: $\pi^b < \pi^m < \pi$

iii. Consumer Surplus: $CS < CS^b < CS^m$

iv. Welfare: $W^b = W < W^m$.

Bilateral licensing, leading to increased hardware price competition, simply lowers prices and profits compared with the other cases above, while keeping the market split evenly. Unilateral licensing increases the profits of the licensor at the expense of the non-licensing rival for all $F < 1/4$. Total profits in this case are lower then when neither firm licenses.

Consumer surplus rises when at least one firm licenses. The reason is that hardware prices fall, and for at least the majority of consumers software availability increases. When there is unilateral licensing leading to monopolization, consumer surplus is at its highest because of the exponential increase in software availability owing to the low cost of software development. Otherwise, consumer surplus is higher when both firms license compared with unilateral licensing.

Welfare is the same when both firms license or neither firm license. The reason for this is that the amount of software available is the same in both case. While the price of hardware is lower when both firms license, in welfare terms this is simply a transfer from producer surplus to consumer surplus, which leaves welfare unchanged. Welfare increases when only one firm licenses because the decrease in profits is outweighed by the corresponding increase in consumer surplus.

When $F < .15$, while there is *de facto* monopolization, it is important to note that welfare increases. This implies that having a variety of systems available when consumers have heterogeneous tastes is not necessarily beneficial to these consumers. The price commitment inherent in the licensing agreement is crucial to this result, because having foreclosed the rival by inducing a large variety of compatible software to be developed, the resulting monopolist has an obvious incentive *ex post* to break the agreement and raise hardware prices.

This section provides a comparison of the components of welfare for three equilibria: where neither firm licenses, one firm licenses, or both firms license. The individual profit comparisons shown in proposition 5 suggest that both firms have an incentive to be the sole licensor. Therefore, there is a probability that both firms license their hardware simultaneously, to the detriment of their profits. This suggests that the firms play a coordination game. This game is presented in the next section along with the solution in the form of a mixed-strategy licensing equilibrium.

4. Licensing equilibrium

Firms face a coordination game when deciding whether or not to license. When $F<1/4$, unilateral licensing results in increased profits for the licensor at the expense of the rival. At the extreme, for $F \leq .15$, unilateral licensing forecloses the rival system from the market. Therefore, both firms have a strong incentive to license, with the result that both firms may end up licensing and earning zero profits. The net result is the following coordination game, presented in normal-form:

		Firm B: License	Firm B: Don't License
Firm A	License	$\pi_A^b = 0$, $\pi_B^b = 0$	$\pi_A^{LA} > 1/2$, $\pi_B^{LA} < 1/2$
	Don't License	$\pi_A^{LB} < 1/2$, $\pi_B^{LB} > 1/2$	$\pi_A = 1/2$, $\pi_B = 1/2$

There are two Nash equilibria: (License, Don't License) and (Don't License, License). Both firms would rather be the licensor if only one firm licenses, but if both firms license each firm regrets having licensed. The solution to this game lies in a mixed-strategy equilibrium.

Proposition 6:

A mixed-strategy equilibrium exists where each firm licenses with probability

$$\lambda = \frac{(8F-1)(4F-1)^2}{4F(20F-3)^2 + (8F-1)(4F-1)^2}.$$

Proof:

Let firm B license with λ probability, where λ makes firm A indifferent between licensing and not licensing:

$$\lambda\pi_A^b + (1-\lambda)\pi_A^{LA} = \lambda\pi_A^{LB} + (1-\lambda)\pi_A.$$

Firm A determines λ in a similar fashion, and solving yields the equilibrium value of λ.

The probability of licensing decreases in F, with $\lambda=1$ when $F=.15$ and $\lambda=0$ when $F=.25$. When $F \leq .15$ and the possibility of a monopolization equilibrium exists both firms license with certainty in order to avoid being foreclosed. Profits for both firms in this case are zero. When $F=1/4$, profits are identical if one firm licenses or neither firm licenses; therefore there is no incentive for either firm to license and risk that the other firm also licenses and both earn zero profits.

Given that both firms play the above mixed-strategy game for $.15 \leq F \leq .25$, expected profits and consumer surplus are as follows:

Expected profits for firm i are:

$$E[\pi_i] = \lambda^2\pi_i^b + \lambda(1-\lambda)\pi_i^{LA} + (1-\lambda)\lambda\pi_i^{LB} + (1-\lambda)^2\pi_i.$$

Expected consumer surplus from system i is:

$$E[CS_i] = \lambda^2 CS_i^b + \lambda(1-\lambda)CS_i^{LA} + (1-\lambda)\lambda CS_i^{LB} + (1-\lambda)^2 CS_i.$$

Finally, expected welfare is:

$$E[W] = E[\pi_A] + E[\pi_B] + E[CS_A] + E[CS_B].$$

The welfare results of licensing are the following:

Proposition 7:

For the range of software development costs where firms consider licensing, expected profits are lower and expected consumer surplus is higher. Expected welfare is higher if licensing is a possibility.

Proof:

See appendix.

Firms will adopt a mixed-strategy to play the coordination game resulting from firms' incentives to license when software development costs are relatively low. Each firm has an incentive to unilaterally license its technology; therefore both may license simultaneously. In this case, the firms are better off if at least one firm hadn't licensed. The solution to this game is a mixed strategy equilibrium. If at least one firm licenses, consumer surplus increases. Therefore, in the mixed-strategy equilibrium, expected consumer surplus is greater than the benchmark equilibrium where neither firm licenses. On the other hand, total profits fall if at least one firm licenses, therefore, expected profits fall in the mixed-strategy equilibrium. The increase in expected consumer surplus outweighs the decrease in expected profits, so total expected welfare rises in the mixed-strategy equilibrium.

5. Conclusion

This paper has shown that for a firm developing a hardware standard, it is profitable to license its technology to third-party firms only if the cost of developing complementary software is relatively low. If the cost of developing software is high, then we have seen that licensing is no longer a profitable strategy. The reason is that licensing, in low cost situations, acts as a commitment to low future hardware prices which increases the number of independent software vendors who support the licensed standard. With low software development costs licensing significantly increases software availability. This increase in software availability has an indirect network effect which further increases sales of the licensed standard beyond the