Tying, Compatibility and Planned Obsolescence

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Abstract

According to the hypothesis of planned obsolescence, a durable goods monopolist without commitment power has an excessive incentive to introduce new products that make old units obsolete, and this reduces its overall profitability. In this paper, I reconsider the above hypothesis by examining the role of competition in a monopolist's upgrade decision. I find that, when a system add-on is competitively supplied, a monopolist chooses to tie the add-on to a new system that is only backward compatible, even if a commitment of not introducing the new system is available and socially optimal. Tying facilitates a price squeeze. (JEL D40, L00, L40)

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> When a model was settled upon then every improvement on that model should be interchangeable with the old model, so that a car should never get out of date. (Henry Ford, My Life and Work, Chapter III)

> Consumers clearly think the price/value proposition of a Windows upgrade is excellent. Millions have bought upgrades, even though their PCs would continue to operate perfectly with their original operating system. (Bill Gates, "Compete, Don't Delete", The Economist, 06/13/98)

Consider a monopoly system maker in a market that lasts two periods. In the first period the firm sells the first-generation of its system A, which is perfectly durable. In the second period the firm develops a new feature, B. It can either sell B as a separate product or sell a new system ($A'B$) that integrates B. Which way is more profitable? In this paper, I show that when competing with an independent supplier of B, a system maker earns a higher profit by selling $A'B$ that is only backward compatible with A, even though selling B as a separate product is socially optimal.

Many durable goods producers frequently introduce upgrades that incorporate new features. Rather than offering a new feature as a separate product, firms often integrate it into a new system and make it unavailable to owners of the old system. For instance, when Microsoft released Windows XP, a number of applications such as Windows Media Player 8, Windows Movie Maker and Wireless Configuration Utility were introduced, but they could not be installed on previous versions of Windows.[1] In order to use these applications, a user would have to upgrade the whole operating system.[2]

Since many of the new features can be unbundled from the Windows operating system and each of them can be sold as an individual application, how does Microsoft gain an advantage by tying them to the purchase of a new system? Certainly there are technical reasons why upgrades are delivered this way, especially if an upgrade is a complete overhaul of the original

[1] "Want Media Player 8? Buy Windows XP", Joe Wilcox, *CNET News*, April 24, 2001; "Windows XP: The big squeeze?", Joe Wilcox, *CNET News*, May 21, 2001.

[2] For a more detailed discussion of Microsoft's bundling strategy, see Section I.

system that cannot be accomplished by merely adding individual applications. The main contribution of this paper is to show that, even when technically feasible, a monopoly system maker may choose not to offer new features separately from the system because tying allows the monopolist to exploit network externalities and extract rents from third-party providers.

I first examine the case in which a monopoly system maker is also the only supplier of an application and consumers differ in their willingnesses to pay for the application. When there are network effects between users of the same system, tying the application to the purchase of a new system that is only backward compatible increases sales, as even low-valuation consumers upgrade for fear of losing network benefits. However, forward-looking consumers will pay less for the original system thus lowering the monopolist's overall profitability. Therefore, a monopolist will commit not to introduce bundled upgrades.

I then turn to the case in which the monopoly system maker faces competition from an independent supplier in the application market, a case that is more relevant to Microsoft. I find that a commitment to tying emerges as a profitable strategy. By integrating its application into a new system, the system maker turns the competition between two applications into a competition between two systems. This change intensifies the competition for market share, crucial in the presence of network externalities, and lowers the prices of applications thus allowing the system maker to charge a higher price for the original system. In other words, the system maker uses tying to engage in a price squeeze (Ordover, Sykes and Willig, 1985) and capture the surplus created by entry of the independent supplier. I find that this price squeeze strategy is most effective when the new system is only backward compatible, but it lowers social welfare.

In both cases, tying entails (full) incompatibility *between the system maker's own application and its old system*. This, coupled with incompatibility *between the two systems,*[3] changes a user's incentive to upgrade. Without tying, a user can buy the application and keep the old system, hence all users remain on the same network and reap maximal network

[3]Backward compatibility, as formally defined later in the paper, implies partial incompatibility.

benefits. Tying induces users who have higher values for the application to migrate to a new system, thus depriving non-upgrading users of network benefits. This forces some users to buy the upgrade they don't need or buy the "wrong upgrade" if there are competing offers.

The traditional explanation for bundling is that it serves as an effective tool of price discrimination by a monopolist (Adams and Yellen, 1976; Schmalensee, 1982; McAfee, McMillan and Whinston, 1989; Bakos and Brynjolfsson, 1999), but this does not explain the use of pure bundling because mixed bundling gives the monopolist more freedom to price discriminate.

Following the seminal contribution by Whinston (1990), a number of papers (Choi and Stefanadis, 2001; Carlton and Waldman, 2002, 2006; Nalebuff, 2004) demonstrate the use of tying to extend a firm's monopoly power from one market to another.[4] However, they have had limited success in explaining Microsoft's tying behavior. Their models assume a physical tie that involves incompatibility with a rival's product, but Microsoft seems to have introduced relatively little incompatibility between its operating system and third-party applications (Whinston, 2001). These models also rely on the entry deterrence effect of tying,[5] but its rivals were already active in their respective markets when Microsoft started the practice.[6] These facts, however, are consistent with my model, which suggests that tying can facilitate rent extraction by a monopoly system maker, who therefore has an incentive to accommodate entry. In this sense, my paper is close in spirit to Farrell and Katz (2000), who study a single producer of component A and several independent suppliers of a complementary component B. They show that the monopolist may have incentives to integrate into supply of component B so as to better extract efficiency rents in the competitive sector.

[4] Other important contributions include Choi (1996, 2004), who focuses on the long-term impact of tying on competition through innovation.

[5] In Nalebuff (2004), bundling can be profitable even if entry deterrence fails, but good A in his model is not essential to the use of good B. Therefore, his model fits well with Microsoft's bundling of Microsoft Office products but less so with its bundling applications into the operating system.

[6] "Is Microsoft Driving Innovation Or Playing Catch-Up With Rivals?", *Reply All, The Wall Street Journal*, Dec. 1, 2006.

The idea that tying can facilitate a price squeeze has also been independently developed by Gans (2007) and Carlton, Gans and Waldman (2007). In both their models and mine, tying can be inefficient even when it does not lead to foreclosure. However, there are two key differences between their models and mine: first, in their models tying is used only if the tie creates economic value and thus is socially efficient in the absence of a rival producer; second, tying in their models is equivalent to bundling hence unbundling such as the one mandated by the European Commission may have a positive effect on welfare, but in mine tying is mainly a commitment of incompatibility hence an order to unbundle but without compatibility requirement is completely ineffective.[7]

There is an extensive literature on competition between networks, but most of it focuses on the coordination-game aspect and considers network effects that are significant enough to generate a winner-takes-all outcome. Relatively few models examine competitions with weak network externalities that lead to segmented networks, despite their wide existence. A recent paper by Grilo, Shy and Thisse (2001) studies a spatial duopoly model with consumption externalities. They find that, when the network effect is present but not too strong, product differentiation can sustain both firms but price competition is fiercer and results in lower prices.[8] A similar result is obtained in my paper.

Finally, the idea that a durable goods producer with network externalities may choose to make a new product incompatible with its old ones is related to the literature on planned obsolescence, originated by Waldman (1993) and Choi (1994).[9] They find that a monopolist has an excessive incentive to introduce new products that make old units obsolete, and this reduces its overall profitability. Most closely related to my paper is the second model of Ellison and Fudenberg (2000),[10] which attributes excessive upgrades to consumer heterogeneity: a monopolist's incentive to upgrade depends on the marginal consumer's valuation, but so-

[7]See a more detailed discussion on EU's mandatary unbundling in Section IV.C.

[8]This result is also obtained in Shy (2001), Armstrong (2006), Doganoglu and Wright (2006).

[9]Other important contributions to this literature include Waldman (1996), Fishman and Rob (2000), Kumar (2002), and Nahm (2004).

[10]In their first model, Ellison and Fudenberg (2000) examine the consumers' coordination problem in detail and show that the monopoly outcome can be upgrades when the social optimum is incompatible networks.

cial welfare depends on the average consumer, therefore the monopolist's choice generally deviates from the social optimal. My paper extends the literature in two directions. First, my model highlights the role of tying and endogenizes the monopolist's choice of compatibility.[11] Second, I consider the role of competition in the market for upgrades; this allows me to show that a monopoly system maker may introduce inefficient upgrades, even if a commitment not to do so is available and socially optimal.

The remainder of this paper is organized as follows: Section I provides some evidence to motivate my model. Section II introduces the basic model. Section III examines the commitment problem of a monopoly system maker when it is also the only supplier of applications. Section IV analyzes the choices of tying and compatibility by a monopoly system maker when it competes with an independent supplier of applications. Section V considers several extensions. Section VI concludes. Any formal proofs omitted from the main text are contained in the appendix.

I. Motivation

In this section, I briefly review two cases that seemed to broadly fit the assumptions of this paper: both firms sell systems that constitute a platform for applications; both are dominant players in their respective markets; product innovations are rapid and users place considerable emphasis on compatibility between generations of products. It is worth noting, however, many details in these cases are not captured by the simple model presented in this paper, and no claim is made to explain fully the observed behavior. Rather, the cases are used to motivate the central thesis of this paper that the choices of tying and compatibility is as much a way to change the rules of the game in the application market as it is determined by technology advances in systems.

[11] Choi (1994) and Ellison and Fudenberg (2000) informally discuss why backward compatibility is preferred to full incompatibility. Lee (2006) formalizes this idea and analyzes a monopolist's choice of compatibility between its successive generations of products, but he only compares three special cases. All these models assume within generation consumer homogeneity, so their analyses and welfare implications are very different from mine. None of these models consider the role of competition in the monopolist's upgrade decision.

A. Microsoft's Tying Strategy

Microsoft's bundling of numerous applications into its Windows operating system has been well documented, but one aspect of its tying strategy has largely escaped notice: Microsoft applications bundled in a new system are often unavailable to users of old systems, who therefore must upgrade their systems in order to use these applications. While this upgrading strategy can be dictated by technical considerations, the following evidence suggests economic motives may also play a role.

First, there is anecdotal evidence that Microsoft intentionally cripples software programs so that they cannot be installed on old operating systems. In one instance, after removing one line of code that checks the version of Windows, users are able to install Windows Defender, a security software, onto Windows 2000 despite Microsoft's claim to the contrary.[12]

Second, third-party applications have been able to provide better compatibility with different versions of the Windows operating system than Microsoft's own applications. Take for example media players:[13] the left column in Table 1 lists the dates and system requirements of major releases of Windows Media Player (WMP) and its main competitor, RealPlayer, in the last decade;[14] the right column is derived from the left and lists the "obsolescence dates" of Windows operating systems, defined as the release date of a media player that discontinues its support of the OS.[15]

An interesting pattern emerges: RealPlayer consistently supports more versions of the Windows OS than Microsoft's own WMP, although Microsoft often rationalizes its bundling strategy by claiming that its own applications can best utilize the operating system. In

[12] Brian Livingston, "Microsoft Turns Up The Heat On Windows 2000 Users", *Information Week*, Dec. 15, 2006.

[13] It should be noted that the media player market is also an example of two-sided markets, in which content providers and final consumers constitute the two sides that trade with each other. Two-sided markets are characterized by indirect network effects, a feature not accounted for in my model. Choi (2006) provides a careful analysis of tying that takes into account the peculiarities of two-sided markets.

[14] The information presented in this table has been obtained from news wires and articles on Lexis-Nexis.

[15] Microsoft received heavy criticism after releasing WMP 8, which was only available on Windows XP. WMP 9, which supported older versions of Windows, was released more than a year after the launch of Windows XP.

Release Date	Media player	System Requirement
1995	WMP 5.1	Windows 95
Late 1997	RealPlayer 5	Windows 3.1
June 1998	WMP 6	Windows 95
July 1998	RealPlayer 6	Windows 95
Nov. 1999	RealPlayer 7	Windows 95
June 2000	RealPlayer 8	Windows 95
July 2000	WMP 7	Windows 98
Oct. 2001	WMP 8	Windows XP
Dec. 2001	RealOne (v9)	Windows NT
Jan. 2003	WMP 9	Windows 98
April 2004	RealPlayer 10	Windows NT
Oct. 2004	WMP 10	Windows XP

Windows Version	Obsolescence Date in WMP	Obsolescence Date in RealPlayer
3.1	1995	July 1998
95	July 2000	Dec. 2001
NT 4.0[a]	July 2000	current
98	Oct. 2001	current
ME	Oct. 2001	current
2000[b]	Oct. 2001	current
XP[c]	Current	current

[a,b]Windows NT and 2000 are intended for professional usage.

[c]Windows XP has both home and professional editions.

Table 1: Release dates and system requirements of major releases of WMP and RealPlayer, 1995-2005.

July 2000, Microsoft released WMP 7, which was bundled into Windows ME but could not be installed on Windows 95.[16] Almost concurrently, RealPlayer 8 was released and still supported Windows 95. The introduction of WMP 8 and RealPlayer 9, by Microsoft and RealNetworks respectively, follows a similar pattern.

B. SAP's Commitment to a "Stable Core"

In contrast, SAP AG, a leading provider of business software, recently announced a major shift in its upgrading strategy. It promised to keep the current version of its flagship product, mySAP ERP 2005, in place for the next 5 years, breaking with the traditional approach of upgrading the entire software release every 12 to 18 months.[17] The company would instead release optional enhancement packages that add new functionalities in certain business areas. Customers can cherry-pick the ones they want to implement and ignore ones they don't. In other words, customers can access new features without overhauling their core systems.

[16] "Microsoft Windows Media Player 7 Brings Click and Play Digital Media To Millions Around the Globe", Microsoft Corporation, *Press Release*, July 17, 2000.

[17] "SAP promises no major software release until 2010", *TechTarget*, Sep. 13, 2006; "SAP's ERP 2005 'stable core' for five years", *InfoWorld*, Sep. 12, 2006.

Notably, SAP's change in upgrading policy took place after a period of rapid consolidation, during which many software vendors that specialize in particular applications exit the industry amid a tech slump.[18]

In sum, two observations can be made from the above cases: first, a system maker may have an incentive to introduce incompatibility between its own applications and systems; second, the incentive to tie applications to a new system is stronger as the potential for add-on competition rises. A model that attempts to account for these observations is presented below.

II. Basic Setup

I consider a two-period model, with periods $t = 1$ and $t = 2$ (see Figure 1). In period 1, a monopolist produces the first generation of the system (A). In period 2, the monopolist develops a new application; it can either introduce a system upgrade that integrates the application ($A'B$) or sell the application as a separate product (B).[19] If it chooses the first option, the monopolist can also manipulate the degree of compatibility between the new system, $A'B$, and the old system, A. I assume that both developing an application and developing an upgrade involve fixed costs that are so small as not to affect the monopolist's upgrade decision.[20] In addition, I normalize the marginal costs of all production to zero.

There is a continuum of consumers who enter the market in period 1. Each consumer buys at most one unit of A in period 1 and one unit of either B or $A'B$ in period 2. I assume that consumers have quasi-linear preferences, so their utilities can be measured in monetary units.

[18] "SAP: A Software Giant Rarin' to Grow", *BusinessWeek*, June 23, 2003.

[19] I call B an application in order to provide concreteness, but B can refer to any new features or improvements that increase the value of a system. See footnote 21 for further discussion.

[20] A positive fixed cost will certainly reduce the monopolist's incentive to introduce an upgrade, but this effect is quite obvious. However, the fixed cost of developing an application by a competitive supplier will play an important role in determining the optimal degree of compatibility when I consider the price squeeze effect of bundling in Section IV.

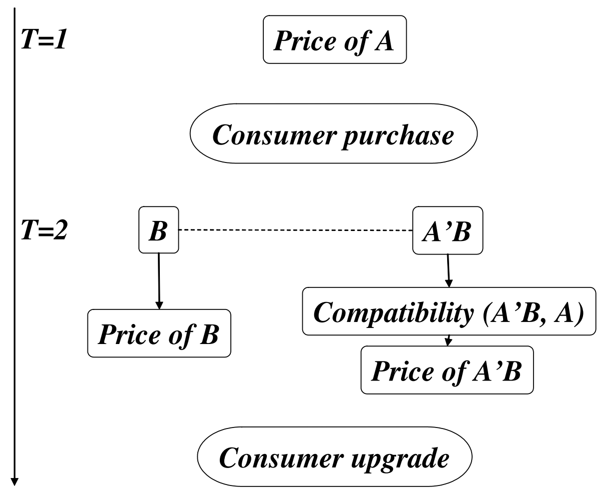

Figure 1: A Two-period Model

To model network externalities, I assume that users of each system constitute a network and that a member of network i derives a network benefit of $N(\sum_{j=1}^{M} a_{ij}x_j)$ from M available networks, where x_j is the number of users on network j and a_{ij} is the network effect from network j to members of network i. I assume that $N(0) = 0$, $N' > 0$, $a_{ij} \in [0, 1]$, and $a_{ii} = 1$ for all i. I allow for partial compatibility, i.e., $a_{ij} < 1$ for some $j \neq i$. When a_{ij} takes the value of either 0 or 1, I obtain three special cases discussed in the literature:

- Full compatibility, $a_{ij} = 1$ for all i and j.
- Full incompatibility, $a_{ij} = 0$ for all $j \neq i$.
- One-way compatibility, $a_{ij} = 0$ and $a_{ji} = 1$, e.g., users of network i benefit only from other users of the same network, while users of network j get the full network benefits from users of both networks; if network j is a newer version of the system than network i, then one-way compatibility implies backward but not forward compatibility.

I assume that the "base value", independent of network externalities, of $A'B$ is the sum of two components, $v^{A'B} = v^A + u$, where v^A is the base value of A and u is the value of B. This specification means that, compared with B, the introduction of $A'B$ adds nothing but a channel through which A is made obsolete.[21] It is in this sense that an upgrade ($A \to A'$) is called inefficient. I further assume that v^A is the same across all consumers. This assumption guarantees that consumers' valuations of $A'B$ are perfectly correlated with their valuations of B. Besides simplifying the analysis, this assumption ensures that the incentive to bundle B cannot be attributed to price discrimination. I also suppose that v^A is so high that all consumers make purchases in the first period (no monopoly exclusion). It is easy to see that the absolute size of v^A as well as the first-period network benefits are immaterial to my analysis, so I normalize them to 0 in order to cut down the number of parameters of which we keep track. For the same reason, I suppose that there is no discount between periods for both consumers and firms.

Last, I assume that the monopolist can prevent consumers from delaying their purchases by offering an upgrade price only available to owners of the first-generation system,[22] but the upgrade price is not set until period 2.[23]

A. Compatibility

Before proceeding to my analysis, I pause a moment to discuss the link between tying and compatibility. Whinston (1990) argues that the effectiveness of tying largely depends on whether a system maker can make a commitment to tie through product design, in particular its choice of compatibility. This means that the tying decision, at its core, is a choice of compatibility. In this paper, it is the (in)compatibility between the application, B, and

[21] This assumption is without loss of generality. According to the goods-characteristics approach, products can be viewed as bundles of characteristics they embody (Lancaster 1966). Taking this approach, we can view B as simply a combination of features not included in A.

[22] It is a standard assumption used in the durable goods literature, e.g., Waldman (1993), Choi (1994), Fudenberg and Tirole (1998) and Ellison and Fudenberg (2000). It is also a routine practice adopted by real world manufacturers. For example, Windows XP Home Edition costs $99 for the upgrade version and $199 for first-time installers. Laura Rohde, "Microsoft Reveals Windows XP Prices", *PC World*, August 24, 2001.

If this assumption is not satisfied, then the results will change slightly in the monopoly case, but will be quite different in the competitive case. See footnote 26 and Section IV.B for more details.

[23] The assumption that the monopolist cannot commit to future prices is not important in my analysis of the monopoly case: its choices of tying and compatibility will not change if the monopolist gains the ability to make a price commitment (see the proof of Proposition 2), but is crucial in my analysis of the competitive case (See Section IV.B for further discussion). A possible justification for this assumption is that such a commitment may reduce the system maker's incentive to invest in R&D.

the original system, A. Note that this is different from the choice of compatibility between the two systems, $A'B$ and A : while the former necessitates a competition between the two systems, the latter regulates the intensity of that competition. At the same time, both can potentially, and indeed do in this paper, lead to incompatibility between a system maker's own products.

III. Monopoly Pricing

In this section I show that, when consumers differ in their willingness to pay for B, a monopolist increases its second-period profit by tying B to the purchase of a system upgrade that is only backward compatible. This, however, lowers the monopolist's overall profitability, therefore it has an incentive to make a commitment not to tie. To model consumer heterogeneity, I assume that their reservation prices of B are represented by the distribution $F(u)$, strictly increasing with continuous density on the closed interval $[a, b]$.

A. The Second Period

In period 2, if the monopolist sells B, then all users will keep the original system A and stay on the same network; a consumer of type u obtains a utility of $N(1)$ from continued use of A and obtains $u + N(1)$ from adding B. But if the monopolist sells $A'B$, then there will be two networks of users. Let users of $A'B$ be network 1 and those of A be network 2; a consumer of type u obtains a utility of $N(\sum_{j=1}^{2} a_{2j}x_j)$ from continued use of A and obtains $u + N(\sum_{j=1}^{2} a_{1j}x_j)$ from upgrading to $A'B$.[24]

Because of the "coordination-game" aspect of network effects, it is possible that multiple equilibria exist. Moreover, consumers with different valuations may not have the same ordering of the possible equilibria, so one cannot use a Pareto criterion to select between the equilibria. Following Ellison and Fudenberg (2000), I assume that network effects are

[24] This corresponds to the "additive specification" in Ellison and Fudenberg (2000).

so small compared to other factors that the upgrade price leads to a unique equilibrium allocation,[25] in which only users who value $A'B$ above some $\tilde{u}$ choose to upgrade.

The monopolist's problem involves two choices: tying and compatibility, but only the latter is pivotal according to the following equivalence result.

Lemma 1 *Selling B is equivalent to selling $A'B$ that is fully compatible with A.*[26]

Proof. Obvious. ■

If $A'B$ is fully compatible with A, then consumers receive the same network benefits from using either version, so their upgrade decision will be purely driven by their valuations of B; whether B is tied makes no difference. Hence we can focus on the monopolist's choice of compatibility while taking its use of tying as given. If the solution entails full compatibility, then it implies unbundling as another solution. Lemma 1 not only helps me streamline the exposition, but also shows that tying is an effective strategy only if the system maker can exploit network externalities by manipulating the degree of compatibility between its own systems.

Proposition 1 *The monopolist maximizes its second-period profit by selling $A'B$ that is only backward compatible, i.e., $a_{12} = 1$ and $a_{21} = 0$.*

Proof. Suppose that the monopolist sells $A'B$. Without upgrading, a user gets $N\{F(\tilde{u}) + a_{21}[1 - F(\tilde{u})]\}$; after upgrading, one gets $u - p + N\{a_{12}F(\tilde{u}) + [1 - F(\tilde{u})]\}$, where p is the price of upgrade. Hence we must have $p = N\{a_{12}F(\tilde{u}) + [1 - F(\tilde{u})]\} - N\{F(\tilde{u}) + a_{21}[1 - F(\tilde{u})]\} + \tilde{u}$ and $\pi|_{t=2} =$

$\max_{\tilde{u}}(N\{a_{12}F(\tilde{u}) + [1 - F(\tilde{u})]\} - N\{F(\tilde{u}) + a_{21}[1 - F(\tilde{u})]\} + \tilde{u})[1 - F(\tilde{u})]$. Denote by u^* the

[25] The precise condition for this to hold depends on the functional forms of $N(\cdot)$ and $F(\cdot)$, which are not specified to allow for generality. See Example 1 for one specification.

[26] The equivalence result breaks down if (i) the marginal costs of production are positive and thus an integrated system is more costly to produce than a standalone application; (ii) the system maker cannot prevent consumers from delaying their purchases by offering discounts to upgrading users; or (iii) there are new system buyers in the second period. In both case (i) and (ii), the unbundling solution will then dominate the full compatibility solution; case (iii) is discussed in an extension of the model (Section V.C).

optimal choice of $\tilde{u}$. Applying the envelope theorem, we get $\frac{\partial}{\partial a_{21}}\pi|_{t=2} = -[1 - F(u^*)]^2 N' < 0$ and $\frac{\partial}{\partial a_{12}}\pi|_{t=2} = F(u^*)[1-F(u^*)]N' > 0$. Therefore, a choice of $a_{12} = 1$ and $a_{21} = 0$ (backward compatibility) maximizes $\pi|_{t=2}$. We can also rule out selling B alone based on Lemma 1. ■

The system maker faces a classic time inconsistency problem: once old units are sold, then a durable goods monopolist has a strong incentive to retire the old units in order to generate new sales. In my model, the system maker pushes users to abandon the original system by exploiting network externalities and consumer heterogeneity. Due to network externalities, the value of a system depends on the number of users. The upgrading decision of users who have high values for the application imposes a negative externality on low valuation users, some of whom are "forced" to upgrade because it is too costly to be left behind. As a result, the original system is made obsolete even though it is perfectly durable. My model, however, does not require the existence of new consumers, as is typically assumed in models of planned obsolescence.

Example 1 *Suppose that* $u \sim U\ [0, 1]$ *and* $N(x) = nx$*, where* $n < 1/2$*. An equilibrium in which some but not all users upgrade exists. Further suppose that* $n = 1/3$*. If* B *is sold as a separate product, then* $1/2$ *of the consumers buy it and the monopolist earns a profit of* $1/4$*. If* B *is bundled into a backward but not forward compatible upgrade* $A'B$*, then* $3/4$ *of the consumers upgrade and the monopolist's profit is* $3/8$*, a* 50% *increase.*

B. The First Period

The time inconsistency problem faced by the monopolist implies that the policy optimal in the short term may not be desirable in a long run perspective. Indeed, the introduction of a backward but not forward compatible upgrade reduces a non-upgrading users' network benefits and their willingness to pay for the original system, thus lowering the monopolist's total profits. Therefore,

Proposition 2 *To maximize total profits, the monopolist commits to either selling B alone or selling $A'B$ that is fully compatible with A.*[27]

Proof. First, I show that full compatibility maximizes its total profits if the monopolist can commit to an upgrade price. With tying, a non-upgrading consumer obtains a network benefit of $N\{F(\tilde{u}) + a_{21}[1 - F(\tilde{u})]$ in period 2, so the monopolist's total profits are $\pi = \max_{\tilde{u}}(N\{a_{12}F(\tilde{u}) + [1 - F(\tilde{u})]\} - N\{F(\tilde{u}) + a_{21}[1 - F(\tilde{u})]\} + \tilde{u})[1 - F(\tilde{u})] + N\{F(\tilde{u}) + a_{21}[1 - F(\tilde{u})]\} = \max_{\tilde{u}} N\{a_{12}F(\tilde{u}) + [1 - F(\tilde{u})]\}[1 - F(\tilde{u})] + F(\tilde{u})N\{F(\tilde{u}) + a_{21}[1 - F(\tilde{u})]\} + \tilde{u}[1 - F(\tilde{u})]$. By the envelope theorem, $\frac{\partial \pi}{\partial a_{12}} = \frac{\partial \pi}{\partial a_{21}} = F(\tilde{u})[1 - F(\tilde{u})]N' > 0$. Therefore, $a_{12}^* = a_{21}^* = 1$ (full compatibility) maximizes the monopoly profits.

Comparing $\pi|_{t=2}$ and π when $a_{12} = a_{21} = 1$, we can see that they differ by a constant $N(1)$. This means that any upgrade price that maximizes $\pi|_{t=2}$ also maximizes π. Therefore, by committing to full compatibility, the monopolist can obtain the maximal profit without necessarily committing to an upgrade price.

Last, by Lemma 1, selling B alone also achieves the full compatibility outcome. ■

Since the monopolist internalizes users' loss of network benefits, introducing frequent upgrades lowers its own profitability. Therefore, it will be better off by choosing actions that constrain its own ability to introduce upgrades. This is by now a standard result, as shown by Waldman (1993) and Choi (1994). However, firms like Microsoft do not seem to be taking any such actions, it is therefore worthwhile to examine their actions from a different perspective (Waldman, 2003).

IV. A Competitive Supplier

Now I turn to the case in which the system maker competes with an independent supplier in the application market. I consider the following game (see Figure 2): the system maker sells A in period 1 and sells B or $A'B$ in period 2; at the beginning of period 1, the system

[27] It is worth noting that the commitment outcome can also be obtained if the monopolist does not sell but leases its product.

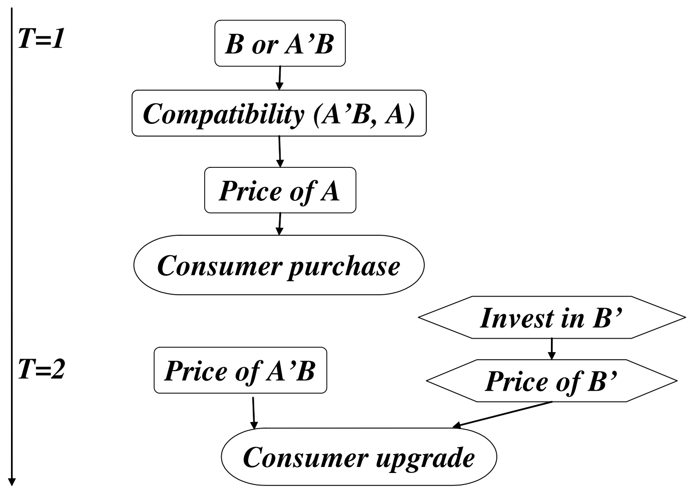

Figure 2: Competition with an Independent Supplier

maker sets the price of A and announces its choices of tying and compatibility for a future upgrade; consumers then make purchases; at the beginning of period 2, an independent supplier can enter the market by spending F to develop a competing application, B', also produced at zero marginal cost. The entry cost F is common knowledge to all participants in the market.[28]

To study the competition in the application market, I consider a variation of the standard linear city model. I assume that consumers are uniformly distributed on a line $[0, 1]$ and that the two firms are located at the opposite ends of the line, with the system maker at 0 and the independent supplier at 1. Consumers have the same reservation price for an application offered by either firm, but a consumer incurs a transportation cost of td when buying from a firm located at a distance of d. I assume that $F < t/2$ so that entry is not blockaded.

Firms set prices simultaneously. I assume that transportation costs are small compared to a consumer's reservation price so the price competition game has a pure strategy equilibrium, in which the application market is covered. In addition, consumers derive network benefits from other users of the same system. For tractability, I assume that network benefits are linear in the size of a network, i.e., $N(x) = nx$. Again, I assume that network effects are

[28]The case in which F is private information is solved in Section V.B.

sufficiently small, i.e., $n < t$, such that a unique equilibrium exists in which consumers in $[0, x]$ buy from the system maker (network 1) and consumers in $[x, 1]$ buy from the independent supplier (network 2). The solution concept that I use is subgame perfect equilibrium.

It is easy to see that Lemma 1 still holds in the case studied here, so I focus on the system maker's choice of compatibility while taking its use of tying as given. Following Whinston (1990) and Carlton and Waldman (2002, 2006), I also assume that a tie is irreversible, i.e., if the system maker ties its application to the purchase of a system, then a consumer cannot undo the tie and use the independent supplier's application. The case of a reversible tie is discussed in Section V.D.

A. The Second Period

I start by solving the price competition subgame that takes place in the second period. Denote by $p_{A'B}$ the price of $A'B$, $p_{B'}$ the price of B', $\pi_m|_{t=2}$ the system maker's second period profits, and $\pi_{B'}$ the independent supplier's (post entry) profits.

Proposition 3 *Full compatibility (incompatibility) maximizes (minimizes)* $\pi_m|_{t=2}$ *and* $\pi_{B'}$.

Proof. Since the tie is irreversible, no one will buy both $A'B$ and B'. Therefore, in an interior solution, consumers located to the left of some x upgrade to $A'B$ (network 1) whereas others keep A (network 2) and buy B'. We must have $-tx - p_{A'B} + n[a_{12}(1-x)+x] = -t(1-x) - p_{B'} + n[(1-x) + a_{21}x]$, hence the marginal consumer is located at $x = [p_{A'B} - p_{B'} - t + n(1-a_{12})]/[n(2-a_{21}-a_{12})-2t]$ and $\pi_m|_{t=2} = p_{A'B}[p_{A'B} - p_{B'} - t + n(1-a_{12})]/[n(2-a_{21}-a_{12})-2t]$. The system maker's FOC is $p_{A'B} - p_{B'} - t + n(1-a_{12}) + p_{A'B} = 0$. Similarly, we can get $\pi_{B'} = p_{B'}[n(1-a_{21}) - t - p_{A'B} + p_{B'}]/[n(2-a_{21}-a_{12})-2t]$ and $n(1-a_{21}) - t - p_{A'B} + 2p_{B'} = 0$. Solving, we obtain $p^*_{B'} = t + \frac{1}{3}[n(2a_{21}+a_{12}-3)]$, $p^*_{A'B} = t + \frac{1}{3}[n(a_{21}+2a_{12}-3)]$, $x^* = [\frac{n}{3}(-a_{21}+a_{12}) - t + n(1-a_{12})]/[n(2-a_{21}-a_{12})-2t]$, $\pi_m|_{t=2} = \{t - [\frac{n}{3}(3-a_{21}-2a_{12})]\}^2/[2t - n(2-a_{21}-a_{12})]$, and $\pi_{B'} = \{t - [\frac{n}{3}(3-2a_{21}-a_{12})]\}^2/[2t - n(2-a_{21}-a_{12})]$. Differentiating and noting that $t > n$, we get $\frac{\partial}{\partial a_{21}}\pi_m|_{t=2} = \frac{n}{9}(t-n+na_{21})(3t-3n+2na_{12}+na_{21})/(2t-2n+na_{12}+na_{21})^2 > 0$,

$\frac{\partial}{\partial a_{12}}\pi_m|_{t=2} = \frac{n}{9}(3t - 3n + 2na_{12} + na_{21})(5t - 5n + 2na_{12} + 3na_{21}) / (2t - 2n + na_{12} + na_{21})^2 > 0$, $\frac{\partial}{\partial a_{21}}\pi_{B'} = \frac{n}{9}(5t - 5n + 2na_{21} + 3na_{12})(3t - 3n + 2na_{21} + na_{12}) / (2t - 2n + na_{21} + na_{12})^2 > 0$ and $\frac{\partial}{\partial a_{12}}\pi_{B'} = \frac{n}{9}(t - n + na_{21})(3t - 3n + na_{21} + 2na_{12}) / (2t - 2n + na_{21} + na_{12})^2 > 0$. This means that both $\pi_m|_{t=2}$ and $\pi_{B'}$ are maximized (minimized) at $a_{21} = a_{12} = 1$ ($a_{21} = a_{12} = 0$). ■

It is not difficult to see the intuition behind the result. If $A'B$ or AB' are not fully compatible, then a user's choice between two applications is also a choice between two network systems. This means that gaining an additional customer not only increases a firm's sales but also makes its network more attractive to other users. Therefore, each firm has a strong incentive to cut price and increase its market share.[29] This intensifies competition and lowers both firms' profits.

A result analogous to Corollary 1 can be obtained.

Corollary 1 *The number of users who upgrade to the new system x^* increases with a_{12} but decreases with a_{21}.*

Proof. From the proof of Proposition 3, we know that $x^* = [\frac{n}{3}(-a_{21} + a_{12}) - t + n(1 - a_{12})]/[n(2 - a_{21} - a_{12}) - 2t]$. Hence, $\frac{\partial x^*}{\partial a_{12}} = \frac{1}{3}n(t - n + na_{21}) / (2t - 2n + na_{12} + na_{21})^2 > 0$, $\frac{\partial x^*}{\partial a_{21}} = -\frac{1}{3}n(t - n + na_{12}) / (2t - 2n + na_{12} + na_{21})^2 < 0$. ■

B. The First Period

In the monopoly case, the system maker reverses its choices of tying and compatibility when it gains the ability to commit. Here again, the system maker faces a time inconsistency problem: in order to increase a consumer's willingness to pay for the original system, it may want to lower the prices of applications. From the proof of Proposition 3, we can see that $p_{B'} = t + \frac{n}{3}(2a_{21} + a_{12} - 3)$ and $p_{A'B} = t + \frac{n}{3}(a_{21} + 2a_{12} - 3)$; the prices of both

[29] It is worth noting that decreasing a_{21} has two competing effects on the system maker's profit: on one hand, it increases the system maker's market share; on the other hand, it intensifies price competition. Interestingly, the market share effect is dominated by the price effect. The reason is not difficult to see: a lower a_{21} gives the independent supplier a greater incentive to enlarge its network through price cuts.

applications increase with the degree of compatibility between systems. This means that, by lowering the degree of compatibility between systems, the system maker can commit itself to a more intense price competition in the application market and force its rival to accept a low price. On the other hand, incompatibility may lead to a loss of network benefits and reduce a consumer's willingness to pay for the original system. The right balance requires some degree of incompatibility that minimizes the loss of network benefits. According to Corollary 2, if the new system is only backward compatible, then the number of users who upgrade will be maximized and the loss of network benefits will be small.

At the same time, the system maker has an incentive to accommodate entry of its rival, because its existence makes the system more valuable to consumers. In this way, the system maker can take advantage of its monopoly position in the system market to capture the additional surplus that its rival's presence generates (due to product differentiation). Therefore,

Proposition 4 *In the unique subgame perfect equilibrium, the system maker commits to selling $A'B$ that is backward but not fully forward compatible and accommodates entry. More specifically, $a_{12}^* = 1$ and $a_{21}^* = \max(0, a)$, where a is the solution to $[t - \frac{2n}{3}(1 - a)]^2 / (2t - n(1-a)) = F$.*

Proof. Suppose that a_{12} and a_{21} are chosen such that the independent supplier does not enter, then the price of the upgrade will be $u + n - t$ so that all users upgrade. There is no monopoly exclusion because u is high. Hence consumers are willing to pay 0 for the original system and the system maker's total profits are $u + n - t$.

Suppose that the independent supplier enters, then the marginal consumer (the user located at x^*) is willing to pay $u+n[x^*+a_{12}(1-x^*)]-tx^*-p_{A'B}$ for the original system, where x^* and $p_{A'B}$ are given in the proof of Proposition 3. Thus the system maker's total profits are $\pi_m = u+n[x^*+a_{12}(1-x^*)]-tx^*-p_{A'B}+\pi_m|_{t=2}$. Differentiating and noting that $t > n$, we get $\frac{\partial \pi_m}{\partial a_{12}} = \frac{n}{9}[4n(t-n)(a_{12}+2a_{21})+6(t-n)^2+n^2(2a_{12}a_{21}+a_{12}^2+3a_{21}^2)] / (2t - 2n + na_{12} + na_{21})^2 > 0$ and $\frac{\partial \pi_m}{\partial a_{21}} = -\frac{2n}{9}(3t - 3n + 2na_{12} + na_{21})(t - n + na_{21}) / (2t - 2n + na_{12} + na_{21})^2 < 0$. In

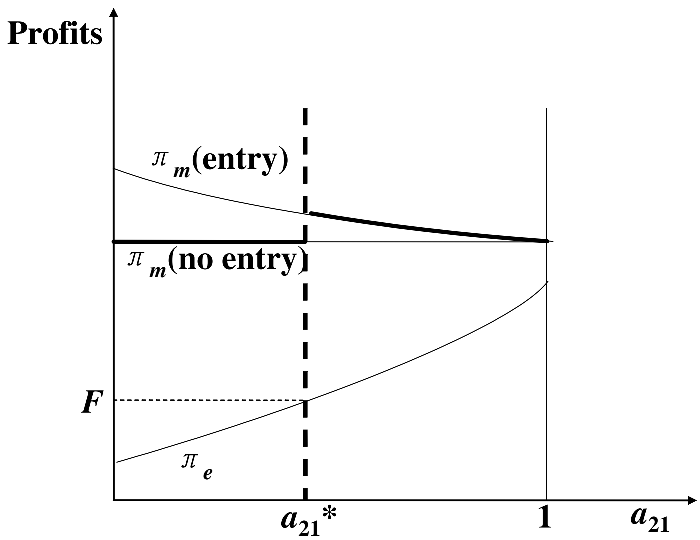

Figure 3: A system maker's total profits when there is a competitive supplier of applications and $a_{12} = 1$.

addition, we have $\pi_m(a_{12} = a_{21} = 1) = u+n-t = \pi_m(\text{no entry})$. This means that the system maker benefits from entry of the independent supplier. Since a higher a_{12} increases both the independent supplier's and the system maker's profits, we must have $a_{12}^* = 1$. As for a_{21}, it depends on the size of the entry cost. If $F < (t-\frac{2}{3}n)^2/(2t-n)$, then the independent supplier always enter regardless of a_{21} hence it should be set to 0; if $F \geq (t-\frac{2}{3}n)^2/(2t-n)$, then a_{21} should be set just high enough such that $\pi_{B'} = [t - \frac{2n}{3}(1-a_{21})]^2/[2t-n(1-a_{21})] = F$ in order to accommodate entry. This implies backward but not forward compatibility, where users of AB' receive only partial benefits from users of $A'B$. ■

The trade-off faced by the system maker is illustrated in Figure 3, in which $\pi_m(\text{entry})$ (respectively, $\pi_m(\text{no entry})$) denotes the system maker's total profits if the independent supplier enters (respectively, does not enter) and π_e denotes the independent supplier's post-entry profit. On one hand, the system maker benefits from the presence of the independent supplier since $\pi_m(\text{entry}) > \pi_m(\text{no entry})$ for all values of a_{21}; on the other hand, the system maker's total profits decrease with a_{21}. At the same time, the independent supplier's post-entry profit increases with a_{21}. Therefore, the optimal strategy for the system maker is to set a_{21} just high enough so that the independent supplier will choose to enter.[30]

By committing to a tie-in of the application with an upgrade that is only backward compatible, the system maker promises a tough fight with the independent supplier of applications upon its entry. This increases a consumer's willingness to pay for the original system and raises the system maker's overall profitability at its rival's expense. In other words, tying enhances the system maker's ability to engage in a price squeeze: by forcing the independent supplier to charge a lower price than it otherwise would, the system maker captures surplus created by entry of the independent supplier.

Here, tying is profitable precisely because it gives the system maker the leverage to change the rules of the game in the application market. If the system maker sells its application as a separate product, then the competition in the application market is just a competition between two differentiated products; but if the system maker ties the sale of its application to a new system, then users who prefer the independent supplier will keep the old system whereas users who prefer the system maker will have to upgrade to a new system and move to a different network. Basically, tying turns the competition between two applications into a competition between two network systems, thus allowing the system maker to take advantage of its control over the system design and its ability to manipulate the degree of compatibility.

The above result contrasts with that of Whinston (1990), who shows under a wide variety of conditions that a monopolist cannot gain from tying complementary products used in fixed proportions. The key difference is the inter-temporal nature of my model. Note that tying is not profitable if the system maker can commit to a low upgrade price and use it to engage in a perfect price squeeze. In Whinston's model, a commitment in price is readily available because components of a system are offered all at once. In my model, however, an upgrade is offered after the system purchase and a commitment in the upgrade price may not be

[30]It is worth noting that the exact form of backward compatibility derived in my model differs from the definition used in Ellison and Fudenberg (2000), according to which users of the old version gains zero network benefits from users of the new version.

feasible.[31,32] Therefore, a system maker has to resort to tying, which partially restores its ability to engage in a price squeeze.

My model is also distinctive from existing foreclosure models in terms of the role of tying: instead of limiting consumers' choices in the application market, tying is used by a system maker in my model to limit consumers' choices in the system market among its own products. Note that consumers upgrade to $A'B$ because B is not available for users of the original system, even though they are free to add B' from the independent supplier. To put it another way, it is the abandonment of old systems, but not the integration with a new system or the exclusion of rival products, that makes the tie-in of applications so appealing to the system maker. This distinction implies that policy makers focusing on the physical integration of applications may have targeted the wrong subject, a point that I will return to later in this section.

Corollary 2 *The system maker's total profits decreases with F.*

Proof. First, a increases with F; second, π_m decreases with $a_{21} = \max(0, a)$. Therefore, π_m (weakly) decreases with F. ■

Since the system maker can manipulate the degree of compatibility between its systems such that the independent supplier's post entry profits barely cover the entry cost, any efficiency gain by the independent supplier in the form of a lower fixed cost will be appropriated by the system maker. Therefore, the system maker may have an incentive to provide open standards in order to facilitate the development of third-party applications,[33] even when it introduces incompatibility between its own products.

[31] Carlton and Waldman (2006) also show that tying can be profitable if a monopoly system maker cannot commit to upgrade prices, but their emphasis is on application upgrades, not system upgrades. Their model predicts foreclosure, whereas mine predicts entry accommodation.

[32] It is not difficult to see that the price commitment outcome can be obtained under a lease-only policy.

[33] "Windows is a piece of intellectual property whose 'facilities' are totally open to partners and competitors alike. Windows' programming interfaces are published free of charge, so millions of independent software developers can make use of its built-in facilities (eg, the user interface) in the applications they design." Bill Gates, "Compete, Don't Delete", The Economist, 06/13/98.

It should be noted that results obtained in this section rely on the assumption that the system maker can offer an upgrade price only available to owners of the first-generation system. If the system maker sells an integrated system as an upgrade in period 2 but cannot price discriminate between upgrading users and first-time buyers, then consumers will have an incentive to delay their purchases thus making the tying strategy less profitable. Nevertheless, in durable goods markets the assumption of price discrimination is quite realistic and it can be easily implemented by a trade-in program, as shown in Choi (1994) and Fudenberg and Tirole (1998). Examples are also abundant. According to Choi (1994), a new release of Microsoft Windows 3.1 operating system for IBM compatible computers is list priced at \$149.95, but a special upgrade price of \$49.99 is also available for registered users of all Window versions if the master copy of a previous version is turned in.

C. Welfare

The system maker's policy of tying the application into an upgrade that is only backward compatible has two effects: first, forward incompatibility reduces total network benefits; second, it distorts some consumers' purchase decisions and increases their transportation costs. Social welfare is lower as a result.[34] In fact,

Proposition 5 *Social welfare is maximized when* $a_{12} = 1$ *and* $a_{21} = 1$.

Proof. The total surplus is determined by both network benefits and transportation costs. It can be written as $TS = x^* N\{F(x^*) + a_{12}[1 - F(x^*)]\} + (1 - x^*)N\{a_{21}F(x^*) + [1 - F(x^*)]\} - \int_0^{x^*} txf(x)dx - \int_{x^*}^1 t(1-x)f(x)dx$, where x^* is the location of the marginal user and $F(\cdot)$ is the CDF that represents the distribution of users on the line of $[0, 1]$. Since $f(x)$ is symmetric, it is easy to see that $TS \leq N(1) - \int_0^{x^*} txf(x)dx - \int_{x^*}^1 t(1-x)f(x)dx \leq N(1) - \int_0^{0.5} txf(x)dx - \int_{0.5}^1 t(1-x)f(x)dx$, where the last term is $TS(a_{12} = 1, a_{21} = 1)$. ■

[34] It is worth noting that entry of the independent supplier is inefficient if $F > t/4$, and in such a case the system maker's incentive to accommodate entry induces inefficient entry.

The welfare analysis above suggests that a ban on tie-in of application and system may improve social welfare, however, such a ban is effective only if the system maker starts to offer applications that work with the old system. Otherwise, even in the absence of physical bundling, a tie remains and may lead to inefficient upgrades. A case in point is the European Commission's antitrust ruling that orders Microsoft to offer Windows XP N, a version of Windows XP without a bundled media player, in European markets. Since Microsoft's new media player is incompatible with old versions of Windows, in order to use it, users will still have to upgrade to Windows XP. In fact, there is virtually no demand for the stripped-down version, particularly as Microsoft has been allowed to offer Windows XP N for the same price as the standard version of Windows XP.

It should be noted, however, that EU's ruling is based on theories that are different from the model presented in this paper. It is therefore not surprising that the prescription suggested by this analysis also differs from EU's actual ruling.

V. Extensions

In this section, I consider extensions of the basic model to check robustness of the results.

A. Uncertainty In Consumer Valuation

In the monopoly case of the basic model, consumers' valuations of B are distributed on the support of $[a, b]$ and each consumer is assumed to know her valuation when making the initial purchase of the system. This is somewhat unrealistic. In this extension, I assume that consumers' valuations still have the same distribution, but a consumer learns her valuation of B only after its introduction by the monopolist in the second period.

Clearly, this does not change the monopolist's second period problem. Now I verify that the solution to the monopolist's commitment problem does not change under the new specification in timing.

In the second period, each consumer in $[a, u^*]$ gets a utility of $N\{F(u^*) + a_{21}[1 - F(u^*)]\}$ and each consumer in $[u^*, b]$ gets $u - p + N\{a_{12}F(u^*) + [1 - F(u^*)]\}$. Uncertainty in valuation means that consumers are identical ex ante, hence they have the same willingness to pay for the system. This determines the original system price, which will be $N\{F(u^*) + a_{21}[1 - F(u^*)]\} + \int_{u^*}^{b} uf(u)du - u^*[(1 - F(u^*)]$. It is also easy to find the price of the upgrade $p = u^* + N\{a_{12}F(u^*) + [1 - F(u^*)]\} - N\{F(u^*) + a_{21}[1 - F(u^*)]\}$.

Therefore, the monopolist's total profits are $\max_{u^*} N\{F(u^*)+a_{21}[1-F(u^*)]\}+\int_{u^*}^{b} uf(u)du - u^*[(1 - F(u^*)] + [1 - F(u^*)](u^* + N\{a_{12}F(u^*) + [1 - F(u^*)]\} - N\{F(u^*) + a_{21}[1 - F(u^*)]\})$. By the envelope theorem, $\frac{\partial \pi}{\partial a_{12}} = \frac{\partial \pi}{\partial a_{21}} = [1 - F(u^*)]F(u^*)N' > 0$. Hence $a_{12} = a_{21} = 1$ (full compatibility) maximizes monopoly profits. Introducing uncertainty does not affect the result.

B. Uncertainty in Entry Cost

In the competitive case of the basic model, I assume that the system maker knows the entry cost of the independent supplier and thus can fine tune its entry accommodation strategy. Now I consider the case in which the independent supplier's entry cost is private information.

Suppose that entry costs, F, are represented by a cumulative distribution function $G(F)$. The independent supplier enters if and only if $F \leq \pi_{B'} = [t - \frac{n}{3}(3 - 2a_{21} - a_{12})]^2/[2t - n(2 - a_{21} - a_{12})]$. So the system maker's expected total profits are $E(\pi_m) = \pi_m(\text{no entry}) + [\pi_m(\text{entry}) - \pi_m(\text{no entry})]G(\pi_{B'})$, where $\pi_m(\text{no entry}) = u + n - t$. Let $\Delta\pi = \pi_m(\text{entry}) - \pi_m(\text{no entry})$. Both $\Delta\pi$ and $\pi_{B'}$ increase with a_{12} so we must have $a_{12}^* = 1$. From the proof of 4, we know that $\Delta\pi$ decreases with a_{21} but $\pi_{B'}$ increases with a_{21}, hence $E(\pi_m)$ is maximized at $a_{21}^* \in (0, 1)$. Therefore, backward but not forward compatibility is still optimal.

Example 2 *Suppose that entry costs are uniformly distributed on* $[0, t/2]$. *In this case,* $E(\pi) \propto \Delta\pi \cdot \pi_{B'} = n\,(a_{12} - a_{21})\,[3t - n(3 - 2a_{12} - a_{21})]^3/[2t - n(2 - a_{12} - a_{21})]^2$. *Since* $\frac{\partial}{\partial a_{12}}(\Delta\pi \cdot \pi_{B'}) = n\,(3t - 3n + na_{12} + 2na_{21})^2\,(2t - 2n + na_{12} + na_{21})^{-3} * (5nta_{12} - 12nt + 7nta_{21} + 6n^2 + 6t^2 - 5n^2a_{12} - 7n^2a_{21} + n^2a_{12}a_{21} + 2n^2a_{12}^2 + 3n^2a_{21}^2) > 0,$

we have $a_{12}^* = 1$. *The first-order condition with respect to* a_{21} *is* $\frac{\partial}{\partial a_{21}}(\Delta\pi \cdot \pi_{B'}) = n\left(3t - 3n + na_{12} + 2na_{21}\right)^2 \left(2t - 2n + na_{12} + na_{21}\right)^{-3}$ $* \left(13nta_{21} - nta_{12} - 12nt + 6n^2 + 6t^2 + n^2 a_{12} - 13n^2 a_{21} + 5n^2 a_{12} a_{21} - 3n^2 a_{12}^2 + 4n^2 a_{21}^2\right) = 0.$ *Substituting* $a_{12}^* = 1$ *into the FOC, we get* $a_{21}^* = 0.443t/n$.

Note that if the entry cost is publicly known and equals the expected value in the private information case, i.e., $F = t/4$, *then* $a_{21}^* = 0.382t/n$, *quite close to the solution in the private information case.*

C. New Customers

In the basic model, the system maker's choice of tying is driven by its desire to increase the price of the original system. One may wonder whether its incentive to tie the application changes if some customers do not make system purchases until the second period. To answer this question, I extend the basic model by assuming that some customers (in the size of s) enter the market in the second period and that they are otherwise identical to customers that enter in the first period.[35]

In the monopoly case, it is clear that the system maker's ex post incentive to introduce backward but not forward compatible upgrade is strengthened because new customers' purchases of the upgrade increases its pull to old customers. At the same time, the system maker's ex ante incentive to make a commitment to full compatibility remains the same. It is not difficult to see why: the system maker's total profits will have an additional term related to the network benefits of new customers, $sN[1 - F(u) + s + a_{12}F(u)]$, but it is increasing in a_{12} and independent of a_{21}.

In the competitive case, the existence of new customers gives the system maker an incentive not to tie its application, but it is advantageous only if the number of new customers is sufficiently large. To see this, we first observe the following: since the system maker will set a discounted upgrade price for owners of the original system and the independent supplier

[35] I do not specify an exogenous attrition process because attrition is endogenous in my model: first-period consumers who choose not to upgrade leave the market in the second period.

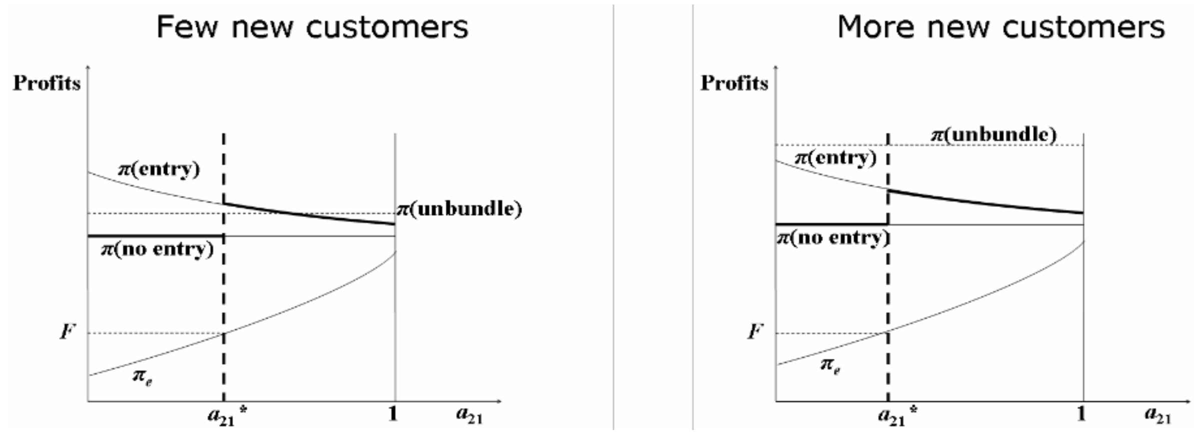

Figure 4: The system maker always benefits from entry of an independent supplier. It earns a higher profit from unbundling than from bundling a fully compatible upgrade. It may or may not choose to bundle a backward but not forward upgrade, depending on the relative size of new customers.

can only sell to these customers, the earlier analysis on firms' pricing strategies involving old customers continues to apply.

Now consider the new customer segment. Here the equivalence between unbundling and full compatibility breaks down. Recall that the equivalence holds in the basic model because old customers buy an upgrade after their system purchases and the system maker cannot precommit to an upgrade price in the first period. New customers, however, buy the system and the application simultaneously, therefore a commitment to a low price in the application is readily available. Since the system is essential for the use of the application, according to Whinston (1990, Proposition 3), it is more profitable not to tie.

Taking into account the competing effects of tying in the two consumer segments, we can conclude that the system maker continues to tie when it expects relatively few new customers and chooses not to tie if it expects a large number of new customers (see Figure 4).

D. Reversible Tie

Following Whinston (1990) and Carlton and Waldman (2002, 2006), in the basic model I have assumed that ties are not reversible, i.e., when the system maker tied its system and application consumers could not reverse the tie and add the independent supplier's application. In this discussion I consider what happens if this assumption is relaxed.

One possibility is that ties are reversible at a cost. That is, when the system maker ties it is possible but costly for a consumer to add an alternative application. For hardware systems, the extra cost may be the labor used to remove parts; for software systems, it may be the hassle of changing file associations or the possible conflicts between two applications. In all these cases, if the cost is sufficiently large, then old customers will not upgrade to a tied system and attempt to undo the tie; therefore a competition between applications will still be a competition between two network systems, so the basic model still applies. At the same time, if there are new customers, then they will have to incur the necessary cost to undo the tie in order to use an alternative application. Hence, in the equilibrium, there may be both customers who choose to reverse the tie and those who choose not to.

Suppose instead that ties are completely reversible, i.e., when the system maker ties its products there is no added cost associated with consumers adding an alternative application onto a tied system. In this case a consumer has a third choice: a choice of upgrading to $A'B$ and buying B'. A consumer may choose to do so if the price of the upgrade is lower than the additional network benefits that it brings. Since consumers value network benefits the same way, price cuts by the system maker have discontinuous payoffs. This means that when the two systems are not fully compatible, a pure strategy equilibrium in simultaneous move pricing game (in period 2) does not exist. This, coupled with the multiplicity of equilibrium due to network externalities, makes the analysis difficult.[36] Nevertheless, I argue in the following that a system maker will never find it optimal to make the upgrade fully compatible with the old system. In other words, it will always tie its application to a new system, even if the tie can be reversed.

[36]Since consumers are heterogeneous, they may not all have the same ordering of the possible equilibria, so we cannot use a Pareto criterion to select between the equilibria. Suppose that the price of the new system is between n and $n(1-x)$, then a user on the immediate left of x prefers all users upgrade (she can now use B'), and a user on the immediate right of x prefers not to upgrade (cost exceeds the benefit.)

To see this, let us suppose that the system maker chooses $a_{12} = 1$ and $a_{21} = 1 - \varepsilon$, where $\varepsilon << 1$. Clearly this is more profitable than full compatibility if the tie is irreversible, according to the proof of Proposition 4. We just need to check whether the system maker will follow the same equilibrium pricing strategy as in the basic model when a tie is reversible. Note that in order to sell the upgrade to customers who will undo the tie, the system maker must set the upgrade price below $n\varepsilon$ and thus earn a profit in the order of ε in period 2, but such a deviation cannot be profitable if ε is small. Knowing this, the independent supplier also has no incentive to change its pricing strategy. Therefore, as long as ε is sufficiently small, having a reversible tie does not affect period 2 subgame equilibrium outcome. This means that the analysis in the proof of Proposition 4 still applies: moving away from full compatibility always increases the system maker's profits. In the Appendix, I also show that if firms set prices sequentially in period 2, then a pure strategy equilibrium exists, in which committing to backward but not forward compatibility ($a_{12} = 1, a_{21} = 0$) is more profitable than full compatibility.

E. Mixed Bundling

One may wonder whether the system maker has an incentive to offer B along with $A'B$. There are two possibilities, depending on whether B is compatible with A. First, if B is incompatible with A, then it is equivalent to selling only $A'B$. Second, if B is compatible with A, then it is equivalent to selling a version of $A'B$ that is fully compatible with A, according to Lemma 1. Denote it by AB. Between AB and $A'B$, the only difference is the network effects. Since users value network effects the same way, they will make the same choice in the equilibrium. This means that the system maker will be able to sell either AB or $A'B$, but not both. Therefore, mixed bundling, offering both AB and $A'B$, does not increase the system maker's profits.

F. Myopic Consumers

Although my analysis is based on the assumption of forward-looking consumers, it is not difficult to find the system maker's optimizing strategy when there are myopic consumers. A commitment in the first period will not increase a myopic consumer's willingness to pay, so the system maker will also act myopically and reverse its strategy completely: in the monopoly case, it will choose to integrate the application into an upgrade that is only backward compatible; but in the competitive case, it will sell its application as a separate product or sell an upgrade that is fully compatible with the old system. In both cases, the system maker can introduce two systems to separate myopic consumers from forward-looking consumers, with the latter group paying a premium for a system that offers a higher second-period utility.

It is also easy to see that the above results are also obtained if the system maker is unable to commit to its future tying strategies.

VI. Discussions and Conclusion

This paper explores a system maker's incentives to provide upgraded versions of its system and its choice of compatibility. It shows that tying applications into an upgrade that is only backward compatible generates higher profits when network externalities are present. As a result, the system maker may introduce more upgrades than optimal. A commitment not to upgrade or a commitment to full compatibility may increase the system maker's total profits. However, if the system maker faces competition from an independent supplier of applications, then it may again introduce the upgrade, even if a commitment of not doing so is available and socially optimal.

The market conduct of a monopoly system maker such as Microsoft has been under constant scrutiny by regulators. A major concern of the regulators is its use of tying as an exclusionary device. My paper suggests that tying can be harmful even when its use by a monopolist does not lead to exclusion of rivals. Ironically, tying is profitable in my model precisely because it commits the system maker to a vigorous competition in the application market.

Although my analysis provides arguments in favor of the hypothesis of planned obsolescence, its welfare implications are less clear. Even in the simple models considered here, which ignores a number of other possible motivations for the practice, the impact of tying on welfare depends on the market structure and model parameters. Moreover, my results are obtained under an assumption of weak network externalities. This means that welfare loss, if any, may not be significant enough to warrant heavy-handed government interventions.

While the models presented in this paper are sufficiently general, there are some strong assumptions that can potentially be relaxed. First, the models ignore entry into the system market; second, the system maker's incentive to engage in R&D is assumed to be exogenous. Future studies that incorporate more realistic elements can help us better understand the issues discussed in this paper.

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A Sequential Move Pricing in Period 2

In the following, I assume that the system maker sets price first in period 2. I look for an equilibrium, in which all players have beliefs that consumers who prefer the alternative application will upgrade and undo the tie if $p_{A'B} \leq n$ but will choose not to upgrade if $p_{A'B} > n$. These beliefs are consistent with consumers' choices.

Proposition 6 *Suppose that the system maker chooses backward but not forward compatibility* $(a_{12} = 1, a_{21} = 0)$ *and* $\frac{t}{9}(11 - 2\sqrt{10}) < n < t$, *then a pure strategy equilibrium exists in the sequential move pricing game. In this equilibrium,* $p_{A'B} = n$ *and* $p_{B'} = \frac{t}{2}$; *all consumers upgrade but* $\frac{1}{4}$ *of them undo the tie and buy an application from the independent supplier.*

Proof. It is easy to see that the independent supplier and consumers will not deviate from their equilibrium strategies. We just need to verify the system maker has no incentive to deviate from its equilibrium price. If $p_{A'B} > n$, then consumers who prefer the alternative application will choose not to upgrade and prices will be set as if the tie were irreversible. Solving, we get $p_{A'B} = (3t - n)/2$, $p_{B'} = (5t - 3n)/4$ and $\pi_m|_{t=2} = (n - 3t)^2/8(2t - n)$. But $\pi_m|_{t=2}$ is smaller than n, the system maker's period 2 profit when $p_{A'B} = n$. ■

According to Proposition 6, if the system maker chooses only backward compatibility, then consumers are willing to pay $u - \frac{3}{4}t$ for the original system. This gives the system maker a total profit of $u + n - \frac{3}{4}t$, which is greater than $u + n - \frac{21}{16}t$,[37] its profit under full compatibility, or $u + n - t$, its profit when the independent supplier is excluded. Interestingly, some consumers will undo the tie, yet the tie forces all consumers, including those who will undo the tie, to buy the upgrade and allows the system maker to extract rents from its rival.

It is also straightforward to verify that if $n \leq \frac{t}{9}(11 - 2\sqrt{10})$, then a pure strategy equilibrium exists such that consumers who buy the alternative application keep the old system. In this equilibrium, $p_{A'B} = \frac{1}{2}(3t - n)$, $p_{B'} = \frac{5}{4}t - \frac{3}{4}n$. The system maker earns a total profit of $u + n + \frac{1}{8}(n - 3t)(3n - 7t)/(n - 2t)$, still greater than its profit under full compatibility.

[37] It is not $u + n - t$, as in the basic model, because here firms set prices sequentially.