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Adoption of Information Technology Under Network Effects

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Because information technologies are often characterized by network effects, compatibility is an important issue. Although total network value is maximized when everyone operates in one compatible network, we find that the technology benefits for the users depend on vendor incentives, which are driven by the existence of "de facto" or "de jure" standards. In head-to-head competition, customers are better off "letting a thousand flowers bloom," fostering fierce competition that results in a de facto standard if users prefer compatibility over individual fit, or a split market if fit is more important. In contrast, firms that sponsor these products are better off establishing an up-front, de jure standard to lessen the competitive effects of a network market. However, if a firm is able to enter the market first by choosing a proprietary/incompatible technology, it can use a "divide-and-conquer" strategy to increase its profit compared with head-to-head competition, even when there are no switching costs. When there is a first mover, the early adopters, who are "locked in" because of switching costs, never regret their decision to adopt, whereas the late adopters, who are not subject to switching costs, are exploited by the incumbent firm. In head-to-head competition, customers are unified in their preference for incompatibility when there is a first mover; late adopters prefer de jure compatibility because they bear the brunt of the first-mover advantage. This again underscores the interdependence of user net benefits and vendor strategies.

Key words: information technology; network effects; adoption; compatibility; standards; first mover
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1. Introduction

Information technologies (IT) are often characterized by network effects. From large enterprise software to individual-use applications such as email, the benefits to technology users often increase with the number of other users. From the perspective of using and managing information systems, there are many advantages to standardization, both in the usage and support of IT. For example, coordination on a standard platform not only facilitates the exchange of information, but also creates a bigger repository of knowledge for configuration and troubleshooting; it also increases the availability of complementary software. It is no wonder that many of the leading examples of network effects come from the IT domain (Shapiro and Varian 1999).

Intuition and conventional wisdom suggest that compatible systems create more value than incompatible ones, and the structure of network effects seems to bear this out: Clearly, the total value of two incompatible networks is less than the value of one, large network that combines them into a single set of interoperable nodes. As a result, the practitioner literature often preaches that vendors should cooperate to agree on a common standard, and if they don't, users, chief information officers, and sometimes government organizations should pressure them to do so. Such calls have been made in the context of Web services (Koch 2003, Johnson 2003), electronic medical records in health care (Hagland 2005), geographic information systems (Guerrero 2004), storage systems (Robb 2005), and telecommunications technology, especially those technologies deployed for public safety enforcement (Moore 2005).

This intuitive argument, however, ignores the effects of compatibility on the intensity of competition, which requires an analysis of vendor incentives. On the one hand, keeping its technology proprietary gives the vendor an advantage, enabling it to extract premium rents if it attracts a large user base, thereby making its product more valuable because of network effects (Katz and Shapiro 1992, Gandal 1994, Brynjolfsson and Kemerer 1996). On the other hand, network markets are prone to "tipping," which may increase the competitive intensity as each firm tries to win the entire market (Besen and Farrell 1994). The competitive intensity can be taken to the extreme case where a vendor competes with a free open source product (Lee and Mendelson 2008). Thus, an analysis of what's best for technology users cannot be separated from an analysis of the strategies of technology vendors, i.e., we must consider the equilibria in both the vendor and user markets. In this paper we study how compatibility affects both the vendors and users of technologies that are characterized by network effects. Our results show that once the equilibrium in the vendor market is taken into account, the conventional wisdom does not hold up in general.

To structure the analysis, we first specify how technology creates value to its users. Conceptually, technology can create value to its users via both "stand-alone" benefits, which are independent of the number of other users, and network effects, which increase with the number of users of a compatible technology. In our model, there are two user segments, each receiving different stand-alone benefits from the technology; each user also receives network benefits, which increase in the total number of users who adopt a compatible standard. Users' technology choices take into account both the stand-alone and network benefits, which they often trade off. For example, the human resource department of a firm may prefer a PeopleSoft (now Oracle) system, whereas engineering may prefer SAP. Users' technology choices then trade off compatibility with others against individual fit. All else being equal, technology users prefer different products to be compatible to leverage network effects. If products were compatible and differed only in their stand-alone benefits, each user could choose his preferred technology and still enjoy the benefits of compatibility.

Compatibility can be the result of a dominant product winning the market and becoming the de facto standard, or a multilateral firm agreement, or an industry-imposed "de jure" standard. Microsoft has emerged as the de facto standard in many software applications, such as word processors (Word versus WordPerfect), spreadsheets (Excel versus Lotus123), and operating systems (Windows versus Mac). When adoption decisions are driven by the desire to be compatible with an existing user base, then users, by their adoption, have implicitly chosen a de facto standard. Firms (sometimes in conjunction with standards committees) can preempt user decisions by agreeing to a de jure standard prior to product development and release. For example, IEEE 802 is a set of standards developed for wired and wireless networking technologies. Within this set of standards, IEEE 802.11g is used commonly in wireless ethernet networking technology for home and business.

In this paper, we study the adoption dynamics in a multisegment market characterized by network effects. User benefits and firm profits depend on the competitive setting: whether firms establish an up-front de jure standard or compete to become the de facto standard and whether they compete head to head or one firm moves first. Whereas conventional wisdom suggests that users would prefer compatible products, we find that when firms compete head to head, customers are better off when the firms' products are incompatible. Competition may result in one firm winning the entire market, thereby becoming the de facto standard,[1] or in coexisting, incompatible products (i.e., a split market). In either case, the fierce competition between technology vendors leaves customers with more surplus than if the firms agreed in advance on a common standard (de jure compatibility). Technology vendors, on the other hand, would be better off establishing a de jure standard.

However, we often see firms introducing proprietary technologies, e.g., Microsoft Office, and Apple iTunes. We find that if a firm can enter the market first with a proprietary technology, it may be able to leverage its incumbency to increase profit, even if there are no switching costs. Under certain conditions, there is a threshold switching cost above which the firm will gain a first-mover advantage, and we characterize this threshold as a function of customer preferences and network effects. We show that the first mover uses

[1] Note that a de facto standard can arise from one firm winning the entire market, as we show in our results, or by competitors using the same (open or licensed) standard.

a "divide-and-conquer" strategy to stagger consumer adoption. Early adopters, who are locked in by the switching costs, actually benefit and never regret their decision to adopt, whereas the late adopters, who are not subject to switching costs, are exploited by the first-moving firm. In head-to-head competition, customers are unified in their preference for incompatibility, but when there is a first mover, late adopters prefer de jure compatibility, because they bear the brunt of the first-mover advantage.

In head-to-head competition, social welfare under de jure compatibility is greater than when users are forced to trade off compatibility and fit under incompatibility. Self-interested actions reduce overall compatibility below the social optimum, but if there is a first-mover advantage, there may be more compatibility than the social optimum.

Literature

As IT has become more networked and ubiquitous, it has been increasingly important to understand the role of standards in the information systems (IS) field (cf. MIS Quarterly Special Issue on Standards Making, August 2006). West (2003) reviews the relevant standards literature in the IS field and points out that, given the prevalence of network effects in IT, the role of compatibility under network effects as it affects technology users and vendors is understudied. Although much of the economics literature has focused on how network effects affect vendor strategies, IS literature has focused on empirical studies of network effects and standardization from the technology user's perspective. Weitzel et al. (2006) use simulation to show that a "standardization gap" between the optimal solution and the actual outcome exists when users choose from a number of different standards.

Our study considers vendor strategies given users' adoption behavior. We find that suboptimal adoption may occur in the forms of both undercompatibility (standardization gap) and overcompatibility, depending on user preferences, vendor pricing, and entry strategies. Implicit in much of the IS standards literature is that standardization is beneficial to technology users (Markus et al. 2006, Jakobs et al. 1998, Axelrod et al. 1995, Foray 1994). However, based on our analysis, the interaction of vendor strategies and user benefits may result in an incompatible solution that makes users better off.

There have been a number of empirical studies of network effects in the IT industry. Dedrick and West (2000) examine the competition in the Japanese PC platform market, finding evidence that offering complementary assets may be necessary to win a standards war. Brynjolfsson and Kemerer (1996) show that network effects exist in the spreadsheet market using a hedonic model. Gallaugher and Wang (2002) study network effects in the two-sided Web server market, also finding evidence of network effects. Kauffman et al. (2000) use hazard modeling to show that banks with larger networks tend to adopt electronic banking earlier. Zhu et al. (2006) study how migration and switching costs affect the adoption of open interorganizational standards, finding that firms that have previously adopted electronic data interchange are much more sensitive to switching costs.

Farrell and Klemperer (2004) summarize the economics literature on network effects (see also Katz and Shapiro 1994, Besen and Farrell 1994, Economides 1996, Hoppe 2002). Katz and Shapiro (1992) find that, with technological progress, a late entrant could prefer incompatibility to an incumbent technology. Matutes and Regibeau (1992) study the compatibility incentives of firms selling components of a system. Regibeau and Rockett (1996) consider compatibility and entry timing in a market where consumers have myopic expectations about network size. Related to our notion of the divide-and-conquer strategy, Katz and Shapiro (1994) survey articles that study the strategy of a firm that produces two complementary goods (e.g., hardware and software), and Mantena and Sundararajan (2004) study strategies for firms entering adjacent markets.

Farrell and Saloner (1986b) use a simple model to study standardization versus variety in a market with network effects. Our model builds on their customer adoption framework while focusing on firms' pricing and entry strategies (which are not studied in Farrell and Saloner 1986b). While their model treats prices as exogenously given, we endogenously determine the equilibrium prices of the firms and show that user benefits, social welfare, and vendor pricing and entry strategies are interdependent. Moreover, we show how the market dynamics and adoption outcome change when there is a first mover. Katz and Shapiro (1985) introduce a static model with fulfilled expectations Cournot equilibrium. Their focus is on how each firm's *output quantity* varies depending on consumers' expectations of the firm's eventual network size; we examine firms' *pricing strategies* when they compete head-to-head and when there is a first mover. Their equilibrium concept leads to multiple equilibria, and in some cases, not all firms prefer standardization. For example, they show that firms with larger expected network size prefer incompatibility. In our model, we show that, when products are incompatible, a first mover can strategically use pricing to build a large network early on and exploit late adopters to gain an advantage; in contrast, in head-to-head competition, all firms prefer de jure compatibility. Katz and Shapiro (1986a) analyze two competing firms that enter the market simultaneously but sell to two sequential generations of consumers. They focus on the sequence of *consumer* arrivals and find that the early mover (defined as the firm that the first-generation consumers prefer) always prefers compatibility, whereas the late mover's preference depends on whether it captures early adopters. We study the entry sequence of the *firms* and find that the first mover may prefer incompatibility because by leveraging its installed base, it increases the value of its own product to late adopters.

Arthur (1989), David (1985), and Liebowitz and Margolis (1990, 1995) debate whether customers can get locked in to adopting an inferior product that is early to market. David (1985) gives the example of the QWERTY keyboard winning over the superior Dvorak keyboard because of its timely introduction; Liebowitz and Margolis (1990, 1995) argue that market forces will always create opportunities for the superior product to eventually dominate. We model the notion of a "superior" product as determined by consumer preferences. Given a set of heterogeneous consumers, there may not be one product that is universally preferred (i.e., "superior"). We show that the driving factors of product adoption are how much customers prefer one product over another and how strong these preferences are relative to the network effects and switching costs.

Aggarwal and Walden (2003) develop a conceptual framework for exploring various forms of industrial organization, where manufacturers are the consumers of standards. They propose that coopetition, where manufacturers cooperate on setting a standard but compete in the final goods market, improves industry performance. Coopetition mitigates the cost of a monopolistically supplied standard while leveraging the network benefits of market standardization. Aggarwal and Walden use the DVD industry as an example of how a coopetition standard won over an monopolistically supplied standard.

The rest of the paper is organized as follows. The model is described in §2. We analyze head-to-head competition in §3 and the first-mover game in §4 and offer our concluding remarks in §5. A summary of notation and all proofs are in the appendix.

2. Model

We construct a stylized model with two competing products and two user market segments to study when either de jure or de facto compatibility is better for technology users, technology vendors, and social welfare. A technology vendor (firm) that owns a technology (through patent or copyright) sells it as a product above marginal cost, which we assume, without loss of generality, to be zero. The two market segments, denoted by $i = 1, 2$, have sizes x_1 and x_2, each consisting of a continuum of homogeneous infinitesimal customers (users). As we consider one segment, i, we will denote the other segment by j, $j \neq i$. There are two products, A and B, that are available in both segments and sponsored by firms A and B, respectively. The gross benefit that a segment-i customer receives from adopting either product is the sum of his stand-alone and network benefits. The stand-alone benefit is the value to the customer of using the product if nobody else adopts it. The network benefit is the value a customer derives from others using the same or a compatible product (cf. Shapiro and Varian 1999, Farrell and Saloner 1992). We assume that the network benefit increases linearly with network size (cf. Farrell and Saloner 1986a, 1992; Katz and Shapiro 1992).

Let $\gamma_i^T \geq 0$ be the stand-alone benefit for a segment-i customer who adopts product $T = A$ or B. We assume that what differentiates the two products is their stand-alone benefits, i.e., $\gamma_i^A \neq \gamma_i^B$. Note that the stand-alone benefit represents the desirability of a product to a given customer segment (cf. Katz and Shapiro

1986a, b). It does not reflect the intrinsic quality of the product, but rather the customers' preferences. Let $\theta \geq 0$ be the benefit to each product-T adopter of a unit mass of customers adopting a compatible product.

We consider two competitive scenarios. In the first scenario, firms A and B compete head to head in a two-stage game. Our focus is on the first-stage pricing game, in which firms A and B enter the market simultaneously and set prices p_1^A, p_2^A, p_1^B, and p_2^B, where p_i^T is the price firm T charges segment i. The second stage is the customer adoption game, in which customers decide which technology, if any, to adopt (Farrell and Saloner 1986b). Following Farrell and Saloner (1986b), all segment-i ($i = 1, 2$) customers either adopt A, adopt B, or adopt nothing;[2] if they adopt $T = A, B$, they receive the gross benefit $\gamma_i^T + \theta x_i \equiv u_i^T$ within their own segment and $\theta x_j \cdot 1_{\{T=T'\}}$[3] from the other segment (the latter expression is zero if $T \neq T'$). If they don't adopt either product, they receive zero benefit.

Adoption in markets with network effects often gives rise to multiple equilibria (cf. Arthur 1989; Rohlfs 1974; Farrell and Klemperer 2004, Part III) that require a further refinement of the equilibrium concept, so the first-stage game can be solved. In our model, there will be multiple equilibria (AA and BB) in the stage-2 subgame when $-\theta x_2 \leq (u_1^A - p_1^A) - (u_1^B - p_1^B) \leq \theta x_2$ and $-\theta x_1 \leq (u_2^A - p_2^A) - (u_2^B - p_2^B) \leq \theta x_1$. When there are multiple equilibria in the stage-2 (adoption) game, we assume customers choose the equilibrium that maximizes their total surplus; this criterion is common in the network effects literature, e.g., Katz and Shapiro (1986a, b), Choi (1994).[4]

We use the notation TT' to signify that segment 1 adopts product $T = A$ or B and segment 2 adopts product $T' = A$ or B. The gross and net benefits of segment-i customers under adoption pattern TT' are $v_i^{TT'} \equiv u_i^T + \theta x_j \cdot 1_{\{T=T'\}}$ and $w_i^{TT'} \equiv v_i^{TT'} - p_i^T \cdot 1_{\{i=1\}} - p_i^{T'} \cdot 1_{\{i=2\}}$, respectively. We define the total network value and net total network value under adoption pattern TT' to be $V^{TT'} \equiv v_1^{TT'} x_1 + v_2^{TT'} x_2$ and $W^{TT'} \equiv V^{TT'} - p_1^T x_1 - p_2^{T'} x_2$, respectively. Note that total network value is equal to the sum of customer net benefit and the profits of firms A and B, which is also equal to social welfare. Henceforth, the terms "social welfare" and "total network" value will be used interchangeably.

The second scenario is when firm A can enter the market first. In the first period, firm A enters the market and sets prices for both segments. Customers then decide whether to adopt A. In the second period, both A and B sell their products to both segments. Those who have not adopted decide whether and which product to adopt. Those who have already adopted A decide whether to switch to B at cost $s \geq 0$. Again, in the event of multiple equilibria in the customer adoption game, customers choose the equilibrium that maximizes total customer surplus.

3. Head-to-Head Competition

Do technology users (segment-1 and -2 customers) and vendors (firms A and B) prefer de jure compatibility or incompatibility? What is the socially optimal outcome? We first consider these questions when firms compete head to head, i.e., firms A and B enter the market simultaneously and compete on price. We study de jure compatibility and incompatibility and discuss the key drivers of the tradeoffs for technology users and vendors in the comparison.

De Jure Compatibility

Suppose products A and B are compatible.[5] Under price competition, customers will adopt one of the two products because their payoffs are nonnegative. Therefore, customer gross benefits will be the sum of the stand-alone benefit and the network benefits from both segments. Because the products are compatible, firms compete only on the stand-alone benefits of their respective products. If segment i prefers product $T = A$ or B, then firm T can win

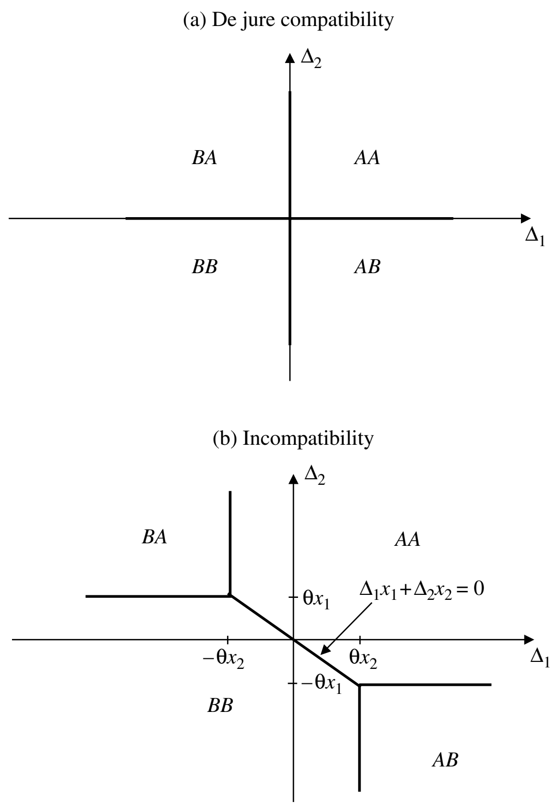
[2] In Farrell and Saloner (1986b), as in our model, the customers that are identical within a given segment, make the same adoption decisions. See also Farrell and Klemperer (2004, Part III, and references therein), Katz and Shapiro (1986a, b), and Farrell and Shapiro (1988).

[3] We use $1_{\{\text{"condition"}\}}$ as the indicator variable, which equals 1 if the "condition" is true and 0 otherwise.

[4] In fact, we show that under our pricing equilibrium, this gives rise to a payoff-dominant stage-2 equilibrium.

[5] Compatibility can be achieved if firms agree to a collectively developed standard or if each firm uses an industry-established standard.

Figure 1 **Head-to-Head Competition Adoption Equilibria**



Note. TT' refers to the region where segment 1 adopts T (A or B) and segment 2 adopts T' (A or B).

that segment by charging $p_i^T = u_i^T - u_i^{T'}$, $T' \neq T$. In general, a firm wins the segment(s) that prefer(s) its product by setting prices so that customers are indifferent between adopting its product and its competitor's, i.e., $p_i^T = \max\{0, u_i^T - u_i^{T'}\}$, resulting in profit $\Pi^T = \max\{0, u_1^T - u_1^{T'}\} + x_1 + \max\{0, u_2^T - u_2^{T'}\} + x_2$. Each customer adopts the best fitting product (the one with the higher stand-alone benefit) and ends up with net benefit $w_i = \min\{u_i^A, u_i^B\} + \theta x_j$, because the winning firm prices products so that customers are indifferent between the two products. The total network value for any adoption pattern is $V^{TT'} = \max\{u_1^A, u_1^B\}x_1 + \max\{u_2^A, u_2^B\}x_2 + 2\theta x_1 x_2$, which is the maximum possible total network value and hence is socially optimal. Figure 1(a) shows the equilibrium adoption patterns under de jure compatibility.

Incompatibility

Now consider the scenario in which products A and B are incompatible, so network effects apply only to users who adopt the *same* product, and firms A and B compete head to head on price. Firms set prices in stage 1, and customers decide what to adopt in stage 2. The stage-2 customer payoff matrix is shown in Figure 2. Given that A and B are in price competition and $u_i^A, u_i^B \geq 0$, "Adopt nothing" is weakly dominated by either "Adopt A" or "Adopt B." The equilibrium conditions are directly derived from the payoff matrix in Figure 2.[6] Multiple stage-2 equilibria (AA and BB) exist when $-\theta x_2 \leq (u_1^A - p_1^A) - (u_1^B - p_1^B) \leq \theta x_2$ and $-\theta x_1 \leq (u_2^A - p_2^A) - (u_2^B - p_2^B) \leq \theta x_1$. In this case, we select the equilibrium that maximizes total customer surplus (cf. Katz and Shapiro 1986a, b and Choi 1994).

Given customers' stage-2 equilibrium strategies, we now derive the stage-1 equilibrium pricing strategies of the firms. We assume that when a firm is indifferent between setting a negative price and zero price, it will choose to set a zero price.[7] Let $\Delta_i \equiv u_i^A - u_i^B$ denote segment i's preference for product A over product B. We define the following sets in (Δ_1, Δ_2) space, $\Delta_1, \Delta_2 \in \mathbb{R}$:

$$D_{AB} \equiv \{(\Delta_1, \Delta_2) \mid \Delta_1 \geq \theta x_2 \text{ and } \Delta_2 \leq -\theta x_1\},$$

$$D_{BA} \equiv \{(\Delta_1, \Delta_2) \mid \Delta_1 \leq -\theta x_2 \text{ and } \Delta_2 \geq \theta x_1\},$$

$$D_{AA} \equiv \{(\Delta_1, \Delta_2) \mid \Delta_1 x_1 + \Delta_2 x_2 \geq 0 \text{ and } \Delta_1 > -\theta x_2 \text{ and } \Delta_2 > -\theta x_1\}, \quad \text{and}$$

$$D_{BB} \equiv \text{the rest of } (\Delta_1, \Delta_2) \text{ space.}$$

The sets D_{AB}, D_{BA}, D_{AA}, and D_{BB} correspond to the regions in Figure 1(b) where AB, BA, AA, and BB, are the equilibrium adoption patterns under incompatible head-to-head competition, respectively. Proposition 1 presents the optimal pricing strategies of both firms and the resulting customer adoption patterns and net benefits.

[6] For example, the necessary and sufficient conditions for AA to be an equilibrium are $(u_1^A - p_1^A) - (u_1^B - p_1^B) \geq -\theta x_2$ and $(u_2^A - p_2^A) - (u_2^B - p_2^B) \geq -\theta x_1$.

[7] The pricing strategy of the losing firm is then robust to small perturbations in the equilibrium strategy that would result in it making negative profit, i.e., eliminating nontrembling hand perfect equilibria (Felli and Roberts 1999, Osborne and Rubinstein 1994).

Figure 2 **Head-to-Head Competition under Incompatibility, Stage-2 Payoff Matrix**

Seg1\Seg2	Adopt A	Adopt B	Adopt nothing
Adopt A	$u_1^A+\theta x_2-p_1^A,\ u_2^A+\theta x_1-p_2^A$	$u_1^A-p_1^A,\ u_2^B-p_2^B$	$u_1^A-p_1^A,\ 0$
Adopt B	$u_1^B-p_1^B,\ u_2^A-p_2^A$	$u_1^B+\theta x_2-p_1^B,\ u_2^B+\theta x_1-p_2^B$	$u_1^B-p_1^B,\ 0$
Adopt nothing	$0,\ u_2^A-p_2^A$	$0,\ u_2^B-p_2^B$	$0,\ 0$

Proposition 1. *In head-to-head competition, under incompatibility, the following are subgame perfect equilibrium pricing strategies for the firms and resulting customer adoption and net benefits*:

- *Split market equilibrium*: *Let $TT'=AB$ or BA and let i be the segment firm A wins and j be the segment firm B wins. If $(\Delta_1,\Delta_2)\in D_{TT'}$, firm A sets $\tilde p_i^A=\Delta_i-\theta x_j$, $\tilde p_j^A=0$, and firm B sets $\tilde p_i^B=0$, $\tilde p_j^B=-\Delta_j-\theta x_i$, resulting in adoption pattern TT' and customer net benefits $w_i^{TT'}=u_i^B+\theta x_j$ and $w_j^{TT'}=u_j^A+\theta x_i$.*
- *De facto compatibility on product T: Let $TT'=AA$ or BB, i.e., $T'=T$. If $(\Delta_1,\Delta_2)\in D_{AA}$, firm A sets $\tilde p_1^A=u_1^A-u_1^B$ and $\tilde p_2^A=u_2^A-u_2^B$ and firm B sets $\tilde p_1^B=\tilde p_2^B=0$, resulting in adoption pattern AA and customer net benefits $w_1^{AA}=u_1^B+\theta x_2$ and $w_2^{AA}=u_2^B+\theta x_1$. If $(\Delta_1,\Delta_2)\in D_{BB}$, firm B sets $\tilde p_1^B=u_1^B-u_1^A$ and $\tilde p_2^B=u_2^B-u_2^A$ and firm A sets $\tilde p_1^A=\tilde p_2^A=0$, resulting in adoption pattern BB and customer net benefits $w_1^{BB}=u_1^A+\theta x_2$ and $w_2^{BB}=u_2^A+\theta x_1$.*

Users make their adoption decision based on net benefits, which combine their stand-alone preferences, network benefits, and product cost. When there is de facto compatibility on product T, network benefits drive the adoption decision.[8] Either customers in both segments prefer T, or the segment that prefers T' would rather be compatible on T with the other segment than adopt the product with the higher stand-alone benefit. Note that even when one firm wins the entire market, it cannot price to extract the network benefits from the consumers. This is because firms A and B enter the market simultaneously and are therefore symmetric. When customers prefer compatibility over fit, firms know that the market will tip to one firm. The winning firm must price so that it offers customers as much value as they would receive if they all adopted its competitor's product at zero price. Therefore, the winning firm cannot price to extract the network benefits from the customers. For example, if firm A were to set prices $p_i^A=u_i^A-u_i^B+z_i$, where $z_i\in(0,\theta x_i)$, $i=1,2$, then firm B could win the entire market by setting prices slightly below A (but still strictly positive). That would give consumers more surplus if they adopted B. When there is a split market equilibrium (AB or BA), stand-alone preferences dominate and each firm maximizes its profit by charging the customers in one segment so that they are indifferent between adopting its product and its competitor's.

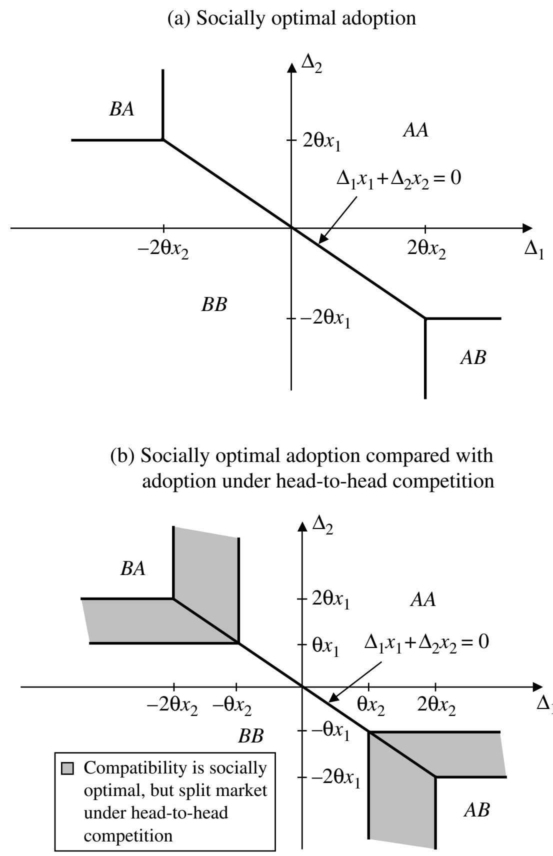
The socially optimal solution maximizes total network value, i.e., the sum of users' net benefits and firm profits, $V^{TT'}=(u_1^T+\theta x_2\cdot 1_{\{T=T'\}})x_1+(u_2^{T'}+\theta x_1\cdot 1_{\{T=T'\}})x_2$. Based on the total network values for the four adoption patterns, V^{AA}, V^{AB}, V^{BA}, and V^{BB}, the socially optimal adoption patterns are summarized in Figure 3(a). The welfare-maximizing adoption pattern is to coordinate on one of the two products unless each segment has a strong preference for a different product. In Figure 3(a), if $\Delta_i\gg 0$ and $\Delta_j\ll 0$ (i.e., customers have strong and different preferences), adopting the product that best fits each segment's preference results in higher total network value than coordinating to achieve compatibility, thereby resulting in a split market outcome, i.e., adoption pattern AB or BA. The following proposition compares the adoption equilibrium in head-to-head competition to the socially optimal outcome.

Proposition 2. *In head-to-head competition, under incompatibility, there is (weakly) less compatibility than what is socially optimal.*

Figure 3(b) shows the results of Propositions 1 and 2. The shaded regions above the diagonal represent customer preferences such that AA is the socially-optimal adoption pattern (i.e., maximum total network value), but price competition between the two firms splits the market. The shaded regions under the diagonal are the analogous areas where BB is socially optimal. In these regions, each segment favors

[8] Note that the equilibrium pricing strategies of the firms result in either a unique Nash equilibrium or a payoff-dominant equilibrium (cf. Harsanyi and Selten 1988, Katz and Shapiro 1986a) in the stage-2 consumer adoption subgame.

Figure 3 **Socially Optimal Adoption under Incompatibility**



Note. TT' refers to the region where segment 1 adopts T (A or B) and segment 2 adopts T' (A or B).

a distinct product, however, the network effects of one segment swamps the product preference of the other segment, resulting in a compatible social optimum. Although compatibility is socially optimal, it is too costly for a firm to subsidize the segment that prefers its competitor. Therefore, each firm targets only the segment that prefers its product, inducing customers to choose individual fit over compatibility. As seen in Figure 3, as the network coefficient θ increases, so does the region of compatibility.

De Jure Compatibility Versus Incompatibility

We compare how the structure of competition (de jure compatibility versus incompatibility) affects technology users and vendors. The following proposition shows that, because of increased competition, customers are actually better off if the firms develop incompatible technologies and fight aggressively to win the entire market.

Proposition 3. *In head-to-head competition, customer net benefits for both segments are (weakly) greater under incompatibility than under de jure compatibility.*

It is natural to assume that with network effects, customers are better off with a common de jure standard. However, Proposition 3 shows that customer net benefits are linked to vendor incentives, which are shaped by the market structure. The competitive intensity of network markets exerts a downward pressure on prices, leaving customers with more surplus. Therefore, contrary to conventional wisdom, it may be better for customers to let the firms fight it out first, to reach a de facto standard, rather than lobby for an up-front de jure standard. When the two segments have different preferences and one firm wins the entire market, this is because customers prefer compatibility over fit. However, the winning firm must price low enough to attract the segment that prefers its competitor's technology, thereby reducing its profits. This increased competition makes incompatibility unattractive for the firms, as shown by the following proposition.

Proposition 4. *In head-to-head competition, if the segments have different preferences, i.e., $\Delta_i > 0$ and $\Delta_j < 0$, the profits of both firms are greater under de jure compatibility than incompatibility. If they have the same preference, i.e., $\Delta_i \geq 0$, the profits of both firms are the same under de jure compatibility and incompatibility.*

Although network benefits are realized when products are compatible, it is the firms that keep the surplus. Under incompatibility, technology users, by adopting the technology, increase the value of the product they adopt and can therefore use this as leverage to capture more surplus. Once firms agree to standardize, they no longer worry about the "winner-take-all" nature of network technologies, thereby removing the customers' leverage, decreasing competitive forces, and allowing each firm to keep more surplus.

Propositions 3 and 4 underscore how competitive network markets are. Technology vendors must essentially compensate customers for the network value that they add with their adoption. Under incompatibility, the outcome is either de facto compatibility, if network effects are strong compared to differing customer preferences, or incompatibility, if customers value individual fit over compatibility with others. The ideal outcome for technology users is to have the vendors compete fiercely on price, as under head-to-head competition, with one technology emerging as the de facto standard. Customers can then realize the benefits of a large network *and* keep more surplus. For example, during the battle for the VCR standard between Betamax and VHS, prices dropped precipitously and product features and quality improved markedly.[9] The basic functionality of the videocassette recorder was similar for both standards, so the sponsoring firms competed fiercely on product attributes such as price and quality, with customers reaping the benefits (Cusumano et al. 1992). Similarly, the fierce competition between incompatible database standards led to price declines and growing adoption in the database software market.

Most notable is the price war between SQL Server, which dominates the small business market, and Oracle, which dominates the enterprise database market (cf. Olofson 2005, eWeek 2007). These price wars, which intensified in 2004, led to a growth of 13% in the database software market compared with 9% for the software market as a whole (Bartels and Rymer 2006). In contrast, compatibility has been the norm in the case of DVD standards. This led to fast adoption, but it also resulted in substantial license fees, amounting to $14 per DVD player and $0.20 per DVD (Aggarwal et al. 2006). In 2005, the average retail price for a DVD player was $110 (Gerson 2007) (including high-end and combination players), and consumers could buy a low-end DVD player for less than $30. The average price of a DVD was $1.40 (Gerson 2007). As pointed out by Aggarwal et al. (2006), the resulting license fees are substantial both in absolute magnitude and as a percentage of the manufacturer's cost.

Policy makers or standards committees may be interested in maximizing total network value or, equivalently, overall social welfare. The following proposition shows that social welfare is maximized under compatibility.

[9] Technically, Sony introduced Betamax first, but the time lag to when VHS was launched by JVC was minimal compared with the time it took to penetrate the home videocassette market. The two technologies competed head to head for three years before VHS eventually became the de facto standard.

Proposition 5. *Social welfare under de jure compatibility is greater than or equal to social welfare under incompatibility.*

With de jure compatibility, network benefits are always realized, whereas under incompatibility, when A and B split the market, network benefits are lost, thereby reducing total network value. This may explain the general inclination toward de jure compatibility. However, it is the *vendors* who capture the additional network value under compatibility. De jure compatibility maximizes vendor surplus and total network value, but incompatibility maximizes customer net benefits.

Note that there is more de facto standardization if the products are incompatible. This is because incompatibility forces a tradeoff between compatibility and fit. It may be socially optimal to have the two segments adopt the same product if the network effects are dominant, even when the two segments have different preferences ($\Delta_i > 0$ and $\Delta_j < 0$). However, if the products are compatible, the benefit of network effects is always realized; therefore, it is socially optimal for customers to adopt the product they prefer, resulting more often in a split market outcome. Although there is more coordination on the same product, incompatibility leads to lower social welfare because of the customers' forced tradeoff.

4. First-Mover Advantage

If technology vendors are more profitable under de jure compatibility, why do we still see proprietary technologies? Often firms race to be the first to market, which raises the question whether there is, in fact, a first-mover advantage. Suppose firm A enters the market before firm B, and customers have the opportunity to adopt product A before product B is available. Clearly, if the products are compatible, even if A enters first, customers will still adopt the product they prefer (either adopt A early or wait for B), resulting in the same outcome described in §3. The rest of this section focuses on the case where firm A chooses a proprietary technology that prevents B from developing a compatible product in the future.

We define first-mover advantage as firm A's ability to increase its profit by leveraging its early entry into the market, i.e., firm A has a first-mover advantage if its profit when it is the first mover is greater than its profit in head-to-head competition. If firm A waits to enter the market, it will compete head to head with B, and under head-to-head competition, firm A would be (weakly) better off establishing de jure compatibility with B (Proposition 4). Hence, we compare firm A's first-mover profit with its profit under head-to-head competition and de jure compatibility to determine whether firm A has a first-mover advantage. Note that if firm A's first-mover profit is greater than its profit under head-to-head competition and de jure compatibility, that implies that its first-mover profit is also greater than its profit under head-to-head competition and incompatibility. We allow customers to switch products at a nonnegative cost. There are many manifestations of switching costs. Examples include learning a new system, converting data and applications to support a new system, etc. (Shapiro and Varian 1999). Switching costs have been discussed as a reason for "lock-in," namely, customers get trapped using an inferior product. The literature is divided on whether lock-ins actually occur. Some (David 1985, Arthur 1989) claim that customers can get trapped using a product that was early to market, whereas others (Liebowitz and Margolis 1995) claim that market forces will induce customers to switch to a more preferred product that is introduced later on. We find that there is a first-mover advantage, but contrary to the "lock-in" theory, early entry can lead to an advantage even if switching costs are zero.

In our model, because the market is segmented and customers may have different preferences, the first mover can use a "divide-and-conquer" strategy to take advantage of the fact that customers maximize their *own* net benefit and customers in the two segments have different preferences. The early "beta" customers are given price incentives to adopt early, whereas the late adopters are exploited and end up paying a premium to join a large network. As a result, we find that, compared to their net benefits under incompatible, head-to-head competition, early adopters are equally well off, whereas late adopters are weakly worse off. For sufficiently high switching costs, the first mover can price to induce an adoption pattern that is not socially optimal; i.e., a late entrant with a superior product cannot win the market.

Let $s \geq 0$ be the per customer cost of switching products, $e \geq 0$ be the per customer benefit for adopting early, and $p_i^T(t)$ be firm T's segment-i price in period t. The timeline is as follows:

- Period 1:

—Stage 1: Firm A enters the market and sets prices $p_1^A(1)$, $p_2^A(1)$.

—Stage 2: Customers decide whether to adopt product A. If a customer adopts A in period 1, he receives early adopter benefit, e.

- Period 2

—Stage 1: Firm A sets prices $p_1^A(2)$, $p_2^A(2)$, and firm B enters and sets prices $p_1^B(2)$, $p_2^B(2)$.

—Stage 2: Customers who have already adopted A decide whether to switch to B at cost s. Customers who have not yet adopted decide which, if either, product to adopt.

Once customers adopt in period 1, their cost is sunk. There are four possible subgames in period 2: No one adopts in period 1, only segment 1 adopts in period 1, only segment 2 adopts in period 1, and both segments adopt in period 1. If no one adopts in period 1, firms A and B compete head to head (as described in Proposition 1) in period 2. It is straightforward to show that the first mover prices to extract the early-adopter benefit, e, from customers who adopt in period 1. The first-mover's profit increases by ex_1, ex_2, or $e(x_1 + x_2)$ if segment 1, segment 2, or both segments adopt in period 1. The rest of our analysis will focus on the strategic advantage of the first mover, i.e., beyond extracting the early-adopter benefit. As such, we will assume $e = 0$, with the understanding that profits for the first mover increase by the above amounts when $e > 0$.

The customer payoff matrix for the period-2 subgames when only one segment adopts A in period 1 is shown in Figure 4(a). Given that A and B are in price competition and u_i^A, $u_i^B \geq 0$, "Adopt nothing" is weakly dominated by either "Adopt A" or "Adopt B." The customer payoff matrix for the period-2 subgame when both segments adopt A in period 1 is shown in Figure 4(b). To solve for the subgame perfect equilibrium, we first solve for the equilibrium prices and adoption patterns in each of the period-2 subgames.[10]

[10] The details of these analyses are in Lemmas 1 and 2 in the online appendix that is available at http://isre.pubs.informs.org.

Figure 4 **First-Mover Game (*A* Is the First Mover), Period-2, Stage-2 Customer Payoff Matrix**

(a) Only segment i adopts A in period 1.

$i \backslash j$	Adopt A	Adopt B	Adopt nothing
Stay with A	$u_i^A+\theta x_j,\ u_j^A+\theta x_i-p_j^A(2)$	$u_i^A,\ u_j^B-p_j^B(2)$	$u_i^A,\ 0$
Switch to B	$u_i^B-p_i^B(2)-s,\ u_j^A-p_j^A(2)$	$u_i^B+\theta x_j-p_i^B(2)-s,\ u_j^B+\theta x_i-p_j^B(2)$	$u_i^B-p_i^B(2)-s,\ 0$

(b) Both segments adopt A in period 1.

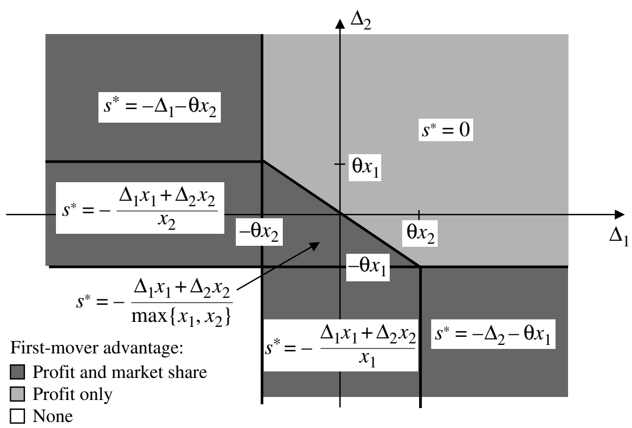
$1\backslash 2$	Stay with A	Switch to B
Stay with A	$u_1^A+\theta x_2,\ u_2^A+\theta x_1$	$u_1^A,\ u_2^B-p_2^B(2)-s$
Switch	$u_1^B-p_1^B(2)-s,\ u_2^A$	$u_1^B+\theta x_2-p_1^B(2)-s,\ u_2^B+\theta x_1-p_2^B(2)-s$

Consider now the period-1, stage-2 subgame. Given $p_1^A(1)$ and $p_2^A(1)$, customers in both segments decide whether to adopt A in period 1 based on the possible outcomes shown in the payoff matrices in Figure 4 or to wait until period 2. We define the threshold switching cost, s^*, as the minimum switching cost required for firm A to have a first-mover advantage. The results of the following proposition are summarized in Figure 5.

Proposition 6. *Firm A has a first-mover advantage if the switching cost, s, is greater than the threshold switching cost, s^*, where s^* is defined as follows:*

- *If $(\Delta_1, \Delta_2) \in D_{AA}$, then $s^*=0$.*
- *If $(\Delta_1, \Delta_2) \in D_{BB}$ and $\Delta_1 \le -\theta x_2$ and $-\theta x_1 \le \Delta_2 < \theta x_1$, then $s^* = -(\Delta_1 x_1+\Delta_2 x_2)/x_2$.*
- *If $(\Delta_1, \Delta_2) \in D_{BB}$ and $\Delta_2 \le -\theta x_1$ and $-\theta x_2 \le \Delta_1 < \theta x_2$, then $s^* = -(\Delta_1 x_1+\Delta_2 x_2)/x_1$.*
- *If $(\Delta_1, \Delta_2) \in D_{BB}$ and $\Delta_1 > -\theta x_2$ and $\Delta_2 > -\theta x_1$, then $s^* = -(\Delta_1 x_1+\Delta_2 x_2)/\max\{x_1, x_2\}$.*
- *If $(\Delta_1, \Delta_2) \in D_{AB}$, then $s^* = -\Delta_2-\theta x_1$.*

Figure 5 **First-Mover Advantage and Threshold Switching Costs for Firm *A***



- *If $(\Delta_1, \Delta_2) \in D_{BA}$, then $s^* = -\Delta_1-\theta x_2$.*
- *Otherwise, firm A does not have a first-mover advantage, even at infinite switching cost.*

The resulting adoption pattern when firm A has a first-mover advantage is AA.

If $(\Delta_1, \Delta_2) \in D_{AA}$, we say that firm A has a *profit-only* first-mover advantage, because its profit increases but its market share remains constant. Notice that firm A has a profit-only first-mover advantage even when there is no switching cost, i.e., the threshold switching cost is $s^*=0$. Clearly, firm A's first-mover advantage does not depend on being able to lock in customers with a switching cost. In this region, both segments prefer to be compatible on A than to be incompatible, even if firm B charges zero price. By moving first, firm A can induce customers in segment i to adopt its product in period 1. In period 2, segment-j customers know that segment i will not switch and therefore will pay a premium (commanded by the network value generated by segment-i customers) to adopt product A. For sufficiently high switching costs, i.e., $s \ge s^* > 0$, firm A gains a first-mover *profit and market share* advantage if $(\Delta_1, \Delta_2) \in (D_{BB} \cup D_{AB} \cup D_{BA}) \backslash \{(\Delta_1, \Delta_2) \mid \Delta_1 < -\theta x_2$ and $\Delta_2 < -\theta x_1\}$. Note that a profit and market share advantage implies that the first mover changes a split market outcome under head-to-head competition into de facto standardization.

Firm A's general strategy is to either price so that one or both segments adopt A in period 1. When firm A prices so that customer adoption is staggered, it purposely delays the adoption of one segment so that it can build network value in period 1 and extract that value from the late adopters in period 2. Firm A can capture more profit by pricing to induce both segments to adopt in period 1 if, under head-to-head competition, there is a split market equilibrium, i.e., if $(\Delta_1, \Delta_2) \in D_{AB} \cup D_{BA}$. Firm A can provide customers in both segments the same net benefit when they adopt A in period 1 (resulting in de facto compatibility) that they would receive in head-to-head competition (resulting in a split market). However, because the two segments are compatible on A, firm A can extract the additional network value, $\theta x_1 x_2$, as profit. For example, when AB is socially optimal and segment 1 adopts A, firm B will price segment 2 just so that it is indifferent between adopting B alone and being compatible with segment 1 on product A at zero price. So even though segment-2 customers have a strong preference for B, firm B's greedy pricing enables firm A to gain a first-mover advantage.

When firm A has a first-mover advantage, there is always de facto standardization. The regions of undercompatibility (compared to the social optimum) are eliminated as the first mover shifts the equilibrium from a split market to compatibility on its own product. Firm A's first-mover advantage can also result in overcompatibility because of the shift from a split market equilibrium to compatibility on A. A straightforward comparison of the results of Proposition 6 to the socially optimal adoption pattern in Figure 3(a) leads to the following conclusion.

Corollary 1. *There is more compatibility than what is socially optimal if and only if* ($\Delta_1 > 2\theta x_2$ *and* $\Delta_2 < -2\theta x_1$ *and* $s \geq s^*$) *or* ($\Delta_1 < -2\theta x_2$ *and* $\Delta_2 > 2\theta x_1$ *and* $s \geq s^*$).

The following proposition describes the threshold switching cost as a function of the network effects and customer preferences.

Proposition 7. *The threshold switching cost, s^*, is weakly decreasing in θ and Δ_i, $i = 1, 2$.*

When firm A has a first-mover advantage, at least one segment adopts A in period 1. As the network coefficient, θ, increases, customers value compatibility more and there is an inertial tendency to standardize on A rather than pay the switching cost to be compatible on B. Therefore, the threshold switching cost decreases as the desire for compatibility, θ, increases. As Δ_i increases, segment i's preference for A over B increases, which means that these customers are more likely to adopt A in head-to-head competition. Because segment i is already more inclined to adopt A, firm A does not have to price as attractively to capture and keep those customers in the first-mover game; therefore, the threshold switching cost does not have to be as high for a first-mover advantage. As s^* decreases, the likelihood of de facto standardization increases.

Proposition 8. *When firm A has a first-mover advantage, compared to its net benefit in the incompatible head-to-head competition, customers who adopt in period* 1 *are equally well off, and customers who adopt in period* 2 *are weakly worse off. Total customer net benefits* (*weakly*) *decrease in switching cost, whereas the profit of the first mover* (*weakly*) *increases.*

The typical lock-in situation is when high switching costs prevent customers who adopt early from switching, and they end up regretting their decision later on. However, in our model, the early adopters adopt A in period 1 knowing firm B will enter in period 2. To induce the early adopters to adopt in period 1, firm A must price attractively enough to ensure that these customers are at least as well off as if they waited for the head-to-head competition. From an expected benefit perspective, early adopters do not regret anything. It is the late adopters who bear the burden of the switching cost when firm A raises its price in period 2 to prevent early adopters from switching and capture the network value created by its installed base. Because firm A captures part of the switching cost when it moves first, its profits increase in the switching cost. Also, as switching cost increases, the early adopters are less likely to switch to B in period 2; therefore, firm A can capture more of the network value created by its installed base. This lowers the net benefits of the late adopters, thereby lowering total customer net benefits.

De Jure Compatibility Versus First-Mover Advantage

The entry decision for the firm is whether to accelerate the launch of a proprietary product to capture first-mover profit or to work with its competitor to establish a de jure standard (resulting in head-to-head competition under compatibility). From Proposition 8, we know that first-mover profits are nondecreasing in the switching cost. We also know from Proposition 4 that head-to-head profits are greater under de jure compatibility. Let s^{**} be the threshold switching cost required for first-mover profits to exceed A's profit under de jure compatibility.

Proposition 9. *If* $(\Delta_1, \Delta_2) \in D_{BB}$ *and* $(\Delta_1 \geq 0$ *or* $\Delta_2 \geq 0)$, *then* $s^{**} > s^*$. *Otherwise,* $s^{**} = s^*$.

Recall that in head-to-head competition, firm A's profit under de jure compatibility is weakly greater than under incompatibility. Therefore, when we compare first-mover profit to de jure compatibility profit, the threshold switching cost needs to be higher, i.e., $s^{**} \geq s^*$. Clearly, if $s^* \leq s < s^{**}$, then firm A prefers de jure compatibility over capitalizing on its first-mover advantage by designing a proprietary/incompatible product. If $s \geq s^{**}$, then firm A would maximize profit by moving first with proprietary design.

The effect of the "divide-and-conquer" strategy on customer net benefits is larger when we compare the results to de jure compatibility.

Proposition 10. *When firm A has a first-mover advantage, compared to its net benefit under de jure compatibility, customers who adopt in period* 1 *are weakly better off and customers who adopt in period* 2 *are weakly worse off.*

Once firm A commits to a proprietary design, the early adopters gain leverage. They can delay adoption until the next period to force A into fierce head-to-head competition with B, thereby giving customers the most surplus. Therefore, once A commits to a proprietary design, it must price for early adoption. This makes early adopters better off than they would be under de jure compatibility. Late adopters are then charged a premium for joining A's network. Notice that whereas in head-to-head competition customers were unified in their preference for incompatible products (forcing firms into fierce price competition), the late adopters here prefer de jure compatibility because they bear the brunt of the first-mover advantage. Therefore, first-mover advantage benefits the first-mover firm and the early adopters but is worse for late adopters. Again, customer net benefits are linked to the strategy of the vendor.

It is interesting to consider how the first-mover advantage affects social welfare.[11] To determine whether firm A has a first-mover advantage, we compared firm A's first-mover profit to its profit under head-to-head competition and de jure compatibility (versus incompatibility) because firm A maximizes profits under head-to-head competition when there is de jure compatibility (Proposition 4). Compared to social welfare when the firms compete head-to-head under de jure compatibility, social welfare when firm A has a first-mover advantage is weakly less. This is because firm A only has a first-mover advantage when A and B are incompatible, so the potential for network benefits between segments is therefore lower. Moreover, any increase in profit for the first mover, including profit from switching costs, is extracted from the late adopters and therefore has no impact on overall social welfare.

Suppose A and B are incompatible. Social welfare in the first-mover game differs from head-to-head competition only when the adoption patterns differ. If the head-to-head equilibrium changes from BB to AA when there is a first mover, then social welfare decreases because the first mover changes the adoption pattern from the socially optimal BB to AA. When the first mover shifts the adoption pattern from a split equilibrium to AA, social welfare increases only if AA or BB is socially optimal. Otherwise, the first mover outcome decreases social welfare.

5. Concluding Remarks

The demand for information technologies is often characterized by network effects. Hand in hand with network effects come the issues of compatibility. In this paper, we studied different market structures in which firms compete under de jure compatibility and incompatibility, and also when there is a first mover. We find that the welfare of technology users and vendors is interdependent and driven by competitive forces. As expected, total network value (or equivalently, overall social welfare) is maximized when technology vendors establish up-front, de jure compatibility. Network benefits are always realized when everyone operates in one compatible network, and users have the luxury of adopting the technology they prefer and can also be assured of being compatible with everyone else. Therefore, the tendency is to think that expanding the entire pie via de jure compatibility will make technology users better off. However,

[11] Social welfare is the sum of consumer net benefits and firm profits.

market structure determines the relative power of the users and vendors and how big a slice of the pie each constituent receives.

When network technologies compete head to head with incompatible products, customers themselves have some leverage, because part of the value of the product comes from their adoption of the technology. The competition for these value-added customers exerts a downward pressure on prices, resulting in lower profits for vendors and higher net benefits for users. The balance of network effects and customer preferences sometimes creates a "winner-take-all" situation. De facto standardization may or may not result in the end, but customers will retain more surplus in either case because price competition is intensified. By agreeing to de jure compatibility, firms can negate network effects and compete only on standalone benefits. This takes the leverage and hence surplus from the customers and increases vendor profits.

However, if one firm can enter the market first (e.g., as Apple did with iTunes), it may be more profitable for it to choose a proprietary technology and leverage its incumbency. The first mover can use a "divide-and-conquer" strategy to stagger customer adoption, thereby exploiting its installed base to capture more profit from the late adopters. If the first mover can create enough network value early on, the late adopters may be swayed to standardize on the incumbent's product, even if they intrinsically prefer the entrant's product. The first mover gains its advantage by pricing attractively to entice early adopters and extracting a price premium from the late adopters. In fact, compared to their net benefits when the firms compete head to head, early adopters are better off and late adopters are worse off. Therefore, when there is a first mover, early adopters benefit from incompatibility, whereas late adopters prefer de jure compatibility. Because early adopters have no reason to switch, even at zero switching cost, the first mover can increase its profit. When there is strictly positive switching cost, the first mover can capture part of the switching cost as profit, thereby increasing its first-mover advantage. Again, we find that vendor and user net benefits are linked and driven by the competitive structure of the market. Even though early adopters seem to bear more risk than late adopters, the first mover's "divide-and-conquer" strategy implicitly favors early adopters, making them better off. We thus found that user benefits cannot be untangled from vendor incentives. The competitive structure (de jure compatibility, incompatibility, first mover) determines the forces that drive vendor strategies, which in turn affect customer net benefits. Only by looking at the entire system and taking into account the interdependencies can we determine what is optimal for technology users, vendors, and overall social welfare.

Extensions

In our model, we considered two representative cases of competition: head to head and first mover. Two related areas that are not addressed by our model are industry dynamics and the speed of market growth. In practice, competition can evolve dynamically, with new users and products being introduced at different times, which can lead to interesting phenomena that are worthy of further research. One area for future research is the development of a dynamic model that will enable the analysis of how adoption evolves over time, what path the industry is taking, and how fast it may converge to a stable structure. Another area for future research is the effect of uncertainty, given that our model is deterministic. Uncertainty may affect both vendor and user strategies, and it can be intertwined with the speed of market growth. With incompatible products, uncertainty about which product will win makes consumers reluctant to commit to a product early on, which may slow down adoption. This may be another factor driving vendors to standardize. In particular, a de jure standard may speed up consumer adoption as it reduces the uncertainty about the ultimate network size and its associated value. Thus, the desire to quickly establish a market rather than fight a costly standards war with an uncertain outcome may motivate vendors to agree on a de jure standard. A dynamic stochastic model may enable researchers to incorporate such considerations into the analysis.

Two additional potential extensions relate to the effects of customer power and quality variations. In some markets, there is a small number of large customers who can act strategically vis-à-vis the vendors; Aggarwal and Walden (2003) discuss how manufacturers that are the consumers of standards can cooperate on setting a standard to circumvent the royalty payments of a monopolistically supplied standard, but still compete in the final goods market. From a modeling perspective, one could consider a market with a finite number of large buyers and analyze the effects of the buyers' strategies on the market outcome. Another limitation of our model is that the attributes of the products sold in the marketplace are exogenously specified, and quality is not modeled explicitly. Another extension is to consider the case where the firms can affect product quality in the course of the product development process, which is endogenously modeled.

6. Electronic Companion

An e-companion to this paper is available as part of the online version that can be found at http://isre.pubs.informs.org.

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Appendix A. Notation

- $T, T' \in \{A, B\}$: products/firms
- $i \in \{1, 2\}$, $j \neq i$: segment numbers
- TT': adoption pattern if segments 1 and 2 adopt products T and T', respectively
- x_i: size of segment i
- γ_i^T: stand-alone benefit of segment-i customer who adopts product $T \in \{A, B\}$ and no one else does
- θ: network coefficient, value to a customer who adopts product T of one unit mass of other customers who also adopt product T
- $u_i^T \equiv \gamma_i^T + \theta x_i$
- $\Delta_i \equiv u_i^A - u_i^B$: segment i's preference for product A over B
- p_i^T: price firm T charges segment i in head-to-head competition
- $p_i^T(t)$: price firm T charges segment i in period t when there is a first mover
- $v_i^{TT'} \equiv u_i^T + \theta x_j \cdot 1_{\{T=T'\}}$: *gross* benefit to a segment-i customer if the adoption pattern is TT'
- $w_i^{TT'} \equiv v_i^{TT'} - p_i^T \cdot 1_{\{i=1\}} - p_i^{T'} \cdot 1_{\{i=2\}}$: *net* benefit to a segment-i customer if the adoption pattern is TT'
- $V^{TT'} \equiv v_1^{TT'} x_1 + v_2^{TT'} x_2$: total network value if adoption pattern is TT'
- $W^{TT'} \equiv V^{TT'} - p_1^T x_1 - p_2^{T'} x_2$: *net* total network value if adoption pattern is TT'

Appendix B. Proofs

Common Notation

We define the following sets in (Δ_1, Δ_2) space, $\Delta_1, \Delta_2 \in \mathbb{R}$, as a function of variables η_1 and η_2, which correspond to the shift in preferences of segment-1 and -2 customers, respectively, when there is a switching cost:

$$D_{AB}(\eta_1, \eta_2) \equiv \{(\Delta_1, \Delta_2) \mid \Delta_1 \geq \theta x_2 + \eta_1 \text{ and } \Delta_2 \leq -\theta x_1 + \eta_2\},$$

$$D_{BA}(\eta_1, \eta_2) \equiv \{(\Delta_1, \Delta_2) \mid \Delta_1 \leq -\theta x_2 + \eta_1 \text{ and } \Delta_2 \geq \theta x_1 + \eta_2\},$$

$$D_{AA}(\eta_1, \eta_2) \equiv \{(\Delta_1, \Delta_2) \mid \Delta_1 x_1 + \Delta_2 x_2 \geq \eta_1 x_1 + \eta_2 x_2 \text{ and } \Delta_1 > -\theta x_2 + \eta_1 \text{ and } \Delta_2 > -\theta x_1 + \eta_2\}, \quad \text{and}$$

$$D_{BB}(\eta_1, \eta_2) \equiv \{(\Delta_1, \Delta_2) \mid \Delta_1 x_1 + \Delta_2 x_2 < \eta_1 x_1 + \eta_2 x_2 \text{ and } \Delta_1 < \theta x_2 + \eta_1 \text{ and } \Delta_2 < \theta x_1 + \eta_2\}.$$

If $\eta_1 = \eta_2 = 0$, $D_{TT'}(0, 0) = D_{TT'}$, $T, T' \in \{A, B\}$. The sets D_{AA}, D_{BB}, D_{AB}, and D_{BA} correspond to the regions in Figure 1 where AA, BB, AB, and BA are the equilibrium adoption patterns, respectively. If $\eta_1 \neq 0$ and $\eta_2 \neq 0$, then $D_{TT'}(\eta_1, \eta_2)$, $T, T' \in \{A, B\}$, correspond to the regions in Figure 1, shifted along the Δ_1 and Δ_2 axes by η_1 and η_2, respectively. When two equations are displayed on a single line as in the following:

$$x_1 = y_1 \quad \text{and} \quad x_2 = y_2, \tag{B1}$$

(B1a) refers to the first equation and (B1b) refers to the second.

We provide here brief outlines of the proofs of Propositions 1, 6, and 8. The full proofs are in Appendix C.

Outline for Proof of Proposition 1

We prove this proposition by backwards induction. We first consider the adoption decisions in stage 2 (adopt A, adopt B, or adopt nothing) given the prices set by the firms in stage 1. We can derive the necessary and sufficient conditions for pure strategy stage-2 equilibria from the payoff matrix shown in Figure 2. Notice that if $-\theta x_2 \leq (u_1^A - p_1^A) - (u_1^B - p_1^B) \leq \theta x_2$ and $-\theta x_1 \leq (u_2^A - p_2^A) - (u_2^B - p_2^B) \leq \theta x_1$, we have a coordination game in which AA and BB are both equilibria. In this case, we select the equilibrium that maximizes total customer surplus, i.e., the equilibrium is AA if $(u_1^A - p_1^A)x_1 + (u_2^A - p_2^A)x_2 \geq (u_1^B - p_1^B)x_1 + (u_2^B - p_2^B)x_2$ and BB otherwise. We write the adoption strategies as a function of firm prices $(p_1^A, p_2^A, p_1^B, p_2^B)$, stand-alone benefits $(u_1^A, u_2^A, u_1^B, u_2^B)$, and network benefits (θ), using the notation $A_i = (u_i^A - p_i^A)x_i$ and $B_i = (u_i^B - p_i^B)x_i$, the price adjusted stand-alone benefits of products A and B, respectively, and $\delta = \theta x_1 x_2$.

We next consider the pricing strategies of the firms in stage 1, given the stage-2 strategies. In stage 1, firm A's equilibrium prices must be the best response to firm B's equilibrium prices, and vice versa. We consider, in turn, the stage-1 pricing strategies that lead to the AA, BB, AB, and BA outcomes in stage 2. Consider first the AA outcome. From the payoff matrix shown in Figure 2 and our equilibrium selection criterion (of maximizing total customer surplus), we see that the outcome will be AA if and only if $A_1 - B_1 \geq -\delta$, $A_2 - B_2 \geq -\delta$, and $A_1 - B_1 + A_2 - B_2 \geq 0$, with the last expression binding. Clearly, if $A_1 - B_1 + A_2 - B_2 > 0$, then firm A has a profitable deviation to raise prices. If $A_1 - B_1 + A_2 - B_2 = 0$, then A cannot raise prices without losing market share and profit. Firm B's optimal prices are $p_1^B = p_2^B = 0$; by lowering price(s), B either makes negative profit or still makes zero profit; by raising price(s), B still makes zero profit because all customers still prefer A (as long as A prices to satisfy $A_1 - B_1 + A_2 - B_2 = 0$). Given firm B's best strategy of pricing at zero, firm A's best response is to set prices so that $(u_1^A - u_1^B)x_1 + (u_2^A - u_2^B)x_2 = p_1^A x_1 + p_2^A x_2$. This implies a range of possible equilibrium prices for firm A, all resulting in the same profit for A. However, by setting $p_1^A = u_1^A - u_1^B$ and $p_2^A = u_2^A - u_2^B$, AA becomes the payoff-dominant stage-2 equilibrium. That is, *both* segments are better off adopting A than B, $w_1^{AA} \geq w_1^{BB}$ and $w_2^{AA} \geq w_2^{BB}$. Thus, the proof shows that the stage-2 equilibrium prices, $p_1^A = u_1^A - u_1^B$ and $p_2^A = u_2^A - u_2^B$ not only make AA the customer surplus maximizing equilibrium, but also make AA the payoff-dominant equilibrium.

We follow analogous reasoning to derive the pricing strategies that lead to the BB, AB, and BA stage-2 equilibria. By comparing the optimal prices and resulting profits leading to the four different equilibria, we can determine the conditions that define D_{AA}, D_{BB}, D_{AB}, and D_{BA} (with firms maximizing profit).

Proof of Proposition 2. Adoption pattern TT' is socially optimal if $V^{TT'} = \max\{V^{AA}, V^{AB}, V^{BA}, V^{BB}\}$. Adoption pattern AA is socially optimal if and only if $(\Delta_1, \Delta_2) \in \{(\Delta_1, \Delta_2) \mid \Delta_1 x_1 + \Delta_2 x_2 \geq 0 \text{ and } \Delta_1 \geq -2\theta x_2 \text{ and } \Delta_2 \geq -2\theta x_1\} \supset D_{AA}$. Similarly, BB is socially optimal for a superset of D_{BB} Hence, the socially optimal compatibility is a superset of $D_{AA} \cup D_{BB}$, which completes the proof. □

Proof of Proposition 3. We consider the case where $\Delta_1 \geq 0$. The results for $\Delta_1 < 0$ are analogous. Let Δw_i be segment i's net benefit under incompatibility minus its net benefit under de jure compatibility. If $\{(\Delta_1, \Delta_2) \in D_{AA} \text{ and } \Delta_2 \geq 0\}$ or $(\Delta_1, \Delta_2) \in D_{AB}$, both segments adopt the product they prefer; hence, $\Delta w_1 = 0$ and $\Delta w_2 = 0$. If $(\Delta_1, \Delta_2) \in D_{AA}$ and $\Delta_2 < 0$, $\Delta w_1 = 0$ and $\Delta w_2 = -\Delta_2 > 0$, and if $(\Delta_1, \Delta_2) \in D_{BB}$ and $\Delta_2 < 0$, $\Delta w_1 = \Delta_1 \geq 0$ and $\Delta w_2 = 0$. In both cases, the winning firm compensates the segment that prefers its competitor for adopting its own product, increasing the net benefit of that segment. □

Proof of Proposition 4. We consider the case where $\Delta_1 \geq 0$. The results for $\Delta_1 < 0$ are analogous. Let $\Delta\Pi^T$ be firm T's profit under de jure compatibility minus its profit under incompatibility. If $(\Delta_1, \Delta_2) \in D_{AA}$ and $\Delta_2 \geq 0$, because both segments prefer A, they adopt A regardless of whether A is compatible with B or not; hence, $\Delta\Pi^A = 0$ and $\Delta\Pi^B = 0$. In the following three cases, the two segments have opposite preferences and firms are either pricing to win the entire market or pricing to prevent their competitor from winning the entire market, thereby driving profits down. If $(\Delta_1, \Delta_2) \in D_{AA}$ and $\Delta_2 < 0$, $\Delta\Pi^A = -\Delta_2 x_2 > 0$ and $\Delta\Pi^B = -\Delta_2 x_2 > 0$. If $(\Delta_1, \Delta_2) \in D_{AB}$, $\Delta\Pi^A = \theta x_1 x_2 > 0$ and $\Delta\Pi^B = \theta x_1 x_2 > 0$. If $(\Delta_1, \Delta_2) \in D_{BB}$ and $\Delta_2 < 0$, $\Delta\Pi^A = \Delta_1 x_1 \geq 0$ and $\Delta\Pi^B = \Delta_1 x_1 \geq 0$. □

Proof of Proposition 5. Social welfare is equivalent to the total network value. We consider the case where $\Delta_1 \geq 0$. The results for $\Delta_1 < 0$ are analogous. Let ΔV be social welfare under de jure compatibility minus social welfare under incompatibility. If $(\Delta_1, \Delta_2) \in D_{AA}$ and $\Delta_2 \geq 0$, $\Delta V = 0$. If $(\Delta_1, \Delta_2) \in D_{AA}$ and $\Delta_2 < 0$, $\Delta V = (u_2^B - u_2^A)x_2 > 0$. If $(\Delta_1, \Delta_2) \in D_{AB}$, $\Delta V = 2\theta x_1 x_2 > 0$. If $(\Delta_1, \Delta_2) \in D_{BB}$ and $\Delta_2 < 0$, $\Delta V = (u_1^A - u_1^B)x_1 \geq 0$. □

Outline for Proof of Proposition 6

Let (tt') represent the adoption sequence where segment 1 adopts in period t and segment 2 adopts in period t'. Let $w_i^{(tt')}$ be the net benefit to segment i when the adoption sequence is (tt'). To determine whether firm A has a first-mover advantage and at what threshold switching cost, we first derive A's maximum profit under adoption sequences (12), (21), and (11). These profits are a function of the switching cost. We then compare firm A's profit under the three adoption sequences with its profit under head-to-head de jure compatibility (Proposition 1), i.e., under sequence (22), to determine the threshold switching cost required for first-mover advantage.

We solve by backwards induction by first solving for the optimal pricing and adoption strategies in period 2. There are four possible subgames in period 2: no one adopts in period 1, only segment 1 adopts in period 1, only segment 2 adopts in period 1, and both segments adopt in period 1. Consider the subgame where segment 1 adopts A in period 1. In period 2, stage 2, given the period-2 prices set by the firms, segment 1 can either stay with A or switch to B at cost s, and segment 2 can either adopt A or B. The necessary and sufficient conditions for pure strategy equilibria in period 2, stage 2 can be derived from the normal form payoff matrix shown in Figure 4(a).

Because segment 1 has already adopted A in period 1, firm A only sets the price for segment 2 in period 2, $p_2^A(2)$. Given that segment 1 has already adopted A, the lowest firm A will set $p_2^A(2)$ is zero. Firm B sets prices for both segments, $p_1^B(2)$ and $p_2^B(2)$. We derive B's optimal prices when A sets $p_2^A(2) = 0$. If firm B can make positive profit by winning one or both segments when $p_2^A(2) = 0$, then it prices to do so; otherwise, B sets $p_1^B(2) = p_2^B(2) = 0$ and firm A makes a positive period-2 profit by setting $p_2^A(2) > 0$. The analyses for the period-2, stage-2 subgames, where segment 2 adopts A in period 1 and both segments adopt A in period 1, are analogous.

Given the possible outcomes in period 2, customers in period 1, stage 2 decide whether to adopt in period 1 or wait until period 2. To induce a segment to adopt in period 1, the first mover must price so that customers are indifferent between adopting in period 1 and period 2. We can therefore derive firm A's optimal pricing strategies in periods 1 and 2 under sequences (12), (21), and (11). We compare these to A's profit under de jure compatibility to determine under what conditions firm A has a first-mover advantage, i.e., depending on Δ_1, Δ_2, s, and θ.

Proof of Proposition 7. We show that for a given network coefficient, $\hat{\theta}$, and a given set of customer preferences, $(\hat{\Delta}_1, \hat{\Delta}_2)$, increasing θ, Δ_1, or Δ_2 by $\varepsilon > 0$ weakly decreases the threshold switching cost, s^*. Let $D'_{BB} \equiv D_{BB} \cap \{(\Delta_1, \Delta_2) \mid \Delta_1 \leq -\theta x_2 \text{ and } -\theta x_1 \leq \Delta_2 < \theta x_1\}$, $D''_{BB} \equiv D_{BB} \cap \{(\Delta_1, \Delta_2) \mid \Delta_2 \leq -\theta x_1 \text{ and } -\theta x_2 \leq \Delta_1 < \theta x_2\}$, and $D'''_{BB} \equiv D_{BB} \cap \{(\Delta_1, \Delta_2) \mid \Delta_1 > -\theta x_2 \text{ and } \Delta_2 > -\theta x_1\}$. The sets D'_{BB}, D''_{BB}, and D'''_{BB} correspond to the regions in Figure 5 where the threshold switching costs are $-(\Delta_1 x_1 + \Delta_2 x_2)/x_2$, $-(\Delta_1 x_1 + \Delta_2 x_2)/x_1$, and $-(\Delta_1 x_1 + \Delta_2 x_2)/\max\{x_1, x_2\}$, respectively.

Suppose $(\hat{\Delta}_1, \hat{\Delta}_2) \in D_{AA}$ for $\theta = \hat{\theta}$. The threshold switching cost is $s^* = 0$ and is independent of θ. As θ increases, D_{AA} increases; therefore, if $(\hat{\Delta}_1, \hat{\Delta}_2) \in D_{AA}$ when $\theta = \hat{\theta}$, then $(\hat{\Delta}_1, \hat{\Delta}_2) \in D_{AA}$ when $\theta = \hat{\theta} + \varepsilon$. By inspection, if $(\hat{\Delta}_1, \hat{\Delta}_2) \in D_{AA}$, then $(\hat{\Delta}_1 + \varepsilon, \hat{\Delta}_2) \in D_{AA}$ and $(\hat{\Delta}_1, \hat{\Delta}_2 + \varepsilon) \in D_{AA}$. Therefore, as θ or Δ_i increases, s^* remains constant at zero.

Suppose $(\hat{\Delta}_1, \hat{\Delta}_2) \in D'_{BB}$ for $\theta = \hat{\theta}$. Then $s^* = -(\Delta_1 x_1 + \Delta_2 x_2)/x_1$, which is independent of θ, and decreasing in Δ_1 and Δ_2. If θ increases by $\varepsilon \geq -\hat{\Delta}_1/x_2 - \hat{\theta}$, then $s^* = -(\Delta_1 x_1 + \Delta_2 x_2)/\max\{x_1, x_2\} \leq -(\Delta_1 x_1 + \Delta_2 x_2)/x_1$. Therefore, s^* weakly decreases in θ. If Δ_1 increases by $-\hat{\Delta}_1 - \hat{\theta} x_2 \leq \varepsilon \leq -(\Delta_1 x_1 + \Delta_2 x_2)/x_1$, then $s^* = -(\Delta_1 x_1 + \Delta_2 x_2)/\max\{x_1, x_2\} \leq -(\Delta_1 x_1 + \Delta_2 x_2)/x_1$. If Δ_1 increases by $\varepsilon > -(\Delta_1 x_1 + \Delta_2 x_2)/x_1$, then $s^* = 0 \leq -(\Delta_1 x_1 + \Delta_2 x_2)/\max\{x_1, x_2\}$. Therefore, s^* weakly decreases in Δ_1. If Δ_2 increases by $\varepsilon \geq -\hat{\Delta}_2 + \hat{\theta} x_1$, the threshold switching cost decreases to $s^* = -\Delta_1 - \theta x_2$, which is constant in Δ_2. The proof for $(\hat{\Delta}_1, \hat{\Delta}_2) \in D''_{BB}$ for $\theta = \hat{\theta}$ is analogous.

Suppose $(\hat{\Delta}_1, \hat{\Delta}_2) \in D_{BB} \backslash \{D'_{BB} \cup D''_{BB} \cup D'''_{BB}\}$ for $\theta = \hat{\theta}$. Then $s^* = \infty$. If θ increases by $\varepsilon \geq \min\{-\hat{\Delta}_2/x_1 - \hat{\theta}, -\hat{\Delta}_1/x_2 - \hat{\theta}\}$, the threshold switching cost decreases to $s^* = -(\Delta_1 x_1 + \Delta_2 x_2)/x_1$ or $s^* = -(\Delta_1 x_1 + \Delta_2 x_2)/x_2$, and $(\hat{\Delta}_1, \hat{\Delta}_2) \in D'_{BB} \cup D''_{BB}$, and the above analysis applies. Similarly, if Δ_1 increases by $\varepsilon \geq -\hat{\theta} x_2 - \hat{\Delta}_1$ or Δ_2 increases by $\varepsilon \geq -\hat{\theta} x_1 - \hat{\Delta}_2$, then $(\hat{\Delta}_1, \hat{\Delta}_2) \in D'_{BB} \cup D''_{BB}$, and the above analysis applies. Therefore, s^* weakly decreases in θ, Δ_1, and Δ_2.

Suppose $(\hat{\Delta}_1, \hat{\Delta}_2) \in D_{AB}$ for $\theta = \hat{\theta}$. Then $s^* = -\Delta_2 - \theta x_1$, which is decreasing in θ and Δ_2 and is independent of Δ_1. If θ increases by $\varepsilon \geq \min\{-\hat{\Delta}_2/x_1 - \hat{\theta}, \hat{\Delta}_1/x_2 - \hat{\theta}\}$, the threshold switching cost decreases to either $s^* = 0$ or $s^* = -(\Delta_1 x_1 + \Delta_2 x_2)/x_1$, where it remains constant in θ. Therefore, s^* weakly decreases in θ. As Δ_1 increases, the threshold switching cost remains constant. If Δ_1 increases by $\varepsilon \geq -\hat{\Delta}_2 - \hat{\theta} x_1$, the threshold switching cost decreases to $s^* = 0$. We can analogously show that s^* weakly decreases in θ, Δ_1, and Δ_2 for $(\hat{\Delta}_1, \hat{\Delta}_2) \in D_{BA}$ for $\theta = \hat{\theta}$ and this completes the proof. □

Outline for Proof of Proposition 8

We prove the first part of this proposition by comparing customer net benefits under incompatible head-to-head competition (Proposition 1) to those in the first-mover game (from the proof of Proposition 6). That is, for every (Δ_1, Δ_2), we find the profit-maximizing adoption sequence for firm A and resulting customer net benefits in the first-mover game (from analysis in Proposition 6) and compare the customer net benefits of the early and late adopters to those under incompatible head-to-head competition.

For the second part of the proposition, we know firm A's first-mover profit and total customer net benefits as a function of the switching cost from Proposition 6. We can therefore show that for every (Δ_1, Δ_2), increasing the switching cost, s, by $\varepsilon > 0$, weakly decreases total customer net benefits and weakly increases first-mover profits.

Proof of Proposition 9. Let Π^A be A's profit as the first mover, $\overline{\Pi}^A$ be A's profit under head-to-head competition and incompatibility, and $\widehat{\Pi}^A$ be A's profit under head-to-head and de jure compatibility. From the proof to Proposition 6, we know that $\Pi^A(s)$ is weakly increasing in s. From Proposition 4, we know that $\widehat{\Pi}^A \geq \overline{\Pi}^A$. If we have s^* and s^{**} such that $\Pi^A(s^*) = \overline{\Pi}^A$ and $\Pi^A(s^{**}) = \widehat{\Pi}^A$, then it must be that $s^* \leq s^{**}$. A straightforward comparison between $\widehat{\Pi}^A$ (from Proposition 4) and Π^A (from Proposition 6) gives us s^{**}. By comparing s^{**} to s^* (Proposition 6), we find exactly the conditions under which $s^* = s^{**}$ and $s^* < s^{**}$. □

Proof of Proposition 10. Let (tt') represent the adoption sequence when segment 1 adopts in period t and segment 2 adopts in period t'. When firm A has a first-mover advantage, the customers who adopt in period 1 receive the same net benefit as they do under head-to-head competition and incompatibility (Proposition 8). From Proposition 3, we know that in head-to-head competition, customer net benefits under incompatibility are greater than or equal to their net benefits under de jure compatibility. Therefore, customers adopting in period 1 receive net benefits equal to or greater than their net benefits under de jure compatibility.

From Proposition 8, we know that late adopters in the first-mover game are weakly worse off compared with head to head and incompatibility. We check only the cases where customer net benefit under de jure compatibility is strictly greater than under incompatibility, i.e., where $\{(\Delta_1, \Delta_2) \mid \Delta_1 \geq 0 \text{ and } \Delta_2 \leq 0 \text{ and } (\Delta_1, \Delta_2) \notin D_{AB}\}$ (the case where $\{(\Delta_1, \Delta_2) \mid \Delta_1 \leq 0 \text{ and } \Delta_2 \geq 0 \text{ and } (\Delta_1, \Delta_2) \notin D_{BA}\}$ is analogous). Let Δw_i be the late adopting segment's net benefit under de jure compatibility minus its net benefit in the first-mover game.

If $(\Delta_1, \Delta_2) \in D_{AA}$ and $\Delta_1 \geq \theta x_2 - s$ and $\Delta_2 \leq 0$, the adoption order in the first-mover game is (12) and $\Delta w_2 = u_2^A + \theta x_1 - u_2^B \geq 0$ because $\Delta_2 \geq -\theta x_1$. If $(\Delta_1, \Delta_2) \in D_{AA}$ and $\Delta_1 < \theta x_2 - s$ and $\Delta_2 \leq 0$, the adoption order in the first-mover game is (12) and $\Delta w_2 = u_2^A + \theta x_1 - (u_2^B + \theta x_1 - ((\Delta_1 x_1 + s x_1)/x_2)) \geq 0$. If $(\Delta_1, \Delta_2) \in D_{BB}$ and $\Delta_1 \geq 0$ and ($x_1 \leq x_2$ or ($x_1 > x_2$ and $\Delta_2 x_2 \leq \Delta_1 x_1 - \theta x_2$)), the adoption order in the first-mover game is (21) and $\Delta w_1 = u_1^B + \theta x_2 - (u_1^B + \theta x_2 - ((\Delta_2 x_2 + sx_2)/x_1)) = (\Delta_2 x_2 + sx_2)/x_1 \geq 0$ because $s \geq -\Delta_2$ (Proposition 6). If $(\Delta_1, \Delta_2) \in D_{BB}$ and $\Delta_1 \geq 0$ and $x_1 > x_2$ and $\Delta_2 x_2 > \Delta_1 x_1 - \theta x_2$ the adoption order in the first-mover game is (12) and $\Delta w_2 = u_2^A + \theta x_1 - (u_2^B + \theta x_1 - ((\Delta_1 x_1 + sx_1)/x_2)) \geq 0$ because $s \geq -(\Delta_1 x_1 + \Delta_2 x_2)/x_1$ (Proposition 6). □

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