Four Paths to Compatibility

Joseph Farrell*
University of California, Berkeley

and

Timothy Simcoe
Boston University School of Management and NBER

A chapter for the Oxford Handbook of the Digital Economy,
edited by Martin Peitz and Joel Waldfogel.

THIS DRAFT: March 3, 2011

ABSTRACT: We describe four ways to achieve product compatibility: decentralized adoption, negotiation in a consensus Standard Setting Organization (SSO), following a leader, and using converters or multi-homing. Each means has costs and benefits in terms of the likelihood of coordination, the time and resources involved, and the implications for *ex post* competition and innovation. We discuss what determines which technologies follow which path to compatibility, and consider hybrid mechanisms that combine two or more paths.

* Professor Farrell is currently on leave serving as Director of the Bureau of Economics at the Federal Trade Commission, but this article is authored in his academic capacity and does not purport to represent the views of the Commission or any Commissioner.

1. Introduction

Compatibility standards are design rules that promote product inter-operability, such as the thread-size for mechanical nuts and bolts or the communication protocols shared by all Internet devices. Products that adhere to standards should work together well, which produces a range of benefits: users may share information, or "mix and match" components; the cost of market entry declines; and there is a division of labor, enabling specialization in component production and innovation. This chapter describes four paths to compatibility – standards wars, negotiations, dictators and converters – and explores how and when they are used, as alternatives or in combination.

While product inter-operability may pose engineering challenges, we focus on economic incentive issues that arise when its costs and benefits are not evenly distributed. For example, firms that control a technology platform may resist compatibility with other systems, or standards that could reduce switching costs for their installed base. Specialized component producers may fight against standards that threaten to "commoditize" their products. Even when support for compatibility is widespread, rival firms may advocate competing designs that confer private benefits because of intellectual property rights, lead-time advantages or proprietary complements.

Given this mix of common and conflicting interests, we focus on four natural ways to coordinate design decisions (in the sense of achieving compatibility). The first is decentralized choice, which can yield coordinated outcomes when network effects are strong, even if the resulting process is messy. Negotiations are a second coordination mechanism. In particular, firms often participate in voluntary Standard Setting Organizations (SSOs), which seek a broad consensus on aspects of product design before endorsing a particular technology. A third route to compatibility is to follow the lead of an influential decision-maker, such as a large customer or platform leader. Finally, participants may abandon efforts to coordinate on a single standard and instead patch together partial compatibility through converters or multi-homing.[1]

These four paths to compatibility have different costs and benefits, which can be measured in time and resources, the likelihood of successful coordination for compatibility, and the *ex post* impact on competition and innovation. Whether these complex welfare trade-offs are well internalized depends on how (and by whom) the path to compatibility is chosen. A full treatment of the compatibility problem would specify the selection process and quantify the relative performance of each path. In practice, while theory clarifies the potential trade-offs, we have limited empirical evidence on the comparative costs and benefits of each path, or the precise nature of the selection process.

---

[1] A user is said to "multi-home" when it adopts several incompatible systems and can thus work with others on any of those systems.

Sometimes the choice of a particular path to compatibility is a more-or-less conscious decision. For example, firms can decide whether to join the deliberations of an SSO or follow the lead of a dominant player. A dominant player can decide whether to commit to a standard and expect (perhaps hope) to be followed, or defer to a consensus negotiation. As these examples suggest, it can be a complex question who, if anyone, "chooses" the mechanism, if any, used to coordinate. Some market forces push toward efficiency, but it is not guaranteed. For example, a platform leader has a general incentive to dictate efficient interface standards or to allow an efficient evolution process, but that incentive may coexist with, and perhaps be overwhelmed by, incentives to stifle *ex post* competition. Likewise, competition among SSOs may or may not lead them toward better policies, and standards wars may or may not tip towards the superior platform.

Sometimes firms will start down one path to compatibility and then veer onto another. For instance, a decentralized standards war may be resolved by resort to an SSO or through the intervention of a dominant firm. Slow negotiations within an SSO can be accelerated by evidence that the market is tipping, and platform sponsors may promote complementary innovation by using an SSO to open parts of their platform. While theory suggests that certain "hybrid paths" can work well, we know rather little about how different coordination mechanisms complement or interfere with one another.

This chapter begins by explaining something familiar to many readers: how the choice of inter-operability standards resembles a coordination game in which players have a mix of common and conflicting incentives. In particular, we explain how compatibility produces broadly shared benefits, and discuss several reasons why firms may receive private benefits from coordinating on a preferred technology. Section 3 describes costs and benefits of our four paths to compatibility. Section 4 examines the selection process and the role of "hybrid" paths to compatibility. Section 5 concludes.

2. Costs and Benefits of Compatibility

When all influential players favor compatibility, creating or upgrading standards involves a coordination problem. When there is but one technology, or when participants share common goals and notions of quality, the solution is primarily a matter of communication that can be solved by holding a meeting, or appointing a focal adopter whom all agree to follow. But if there are several technologies to choose from and participants disagree about their relative merit, it turns a pure coordination game into a battle of the sexes, where players may try to "win" by arguing for, or committing to, their preferred outcome.

INSERT FIGURE 1 ABOUT HERE

Figure 1 illustrates the basic dilemma in a symmetric two-player game. As long as C>B, the benefits of compatibility outweigh the payoffs from uncoordinated adoption of each player's preferred technology, and the game has two pure-strategy Nash Equilibria: *both adopt A*, and *both adopt B*. Each player gains some additional private benefit (equal to D) in the equilibrium that selects their preferred technology. When these private benefits are small ($D \approx 0$), many coordination mechanisms would work well. But as D grows large, players will push hard for their preferred equilibrium. Whether these efforts to promote a particular outcome are socially productive depends on a variety of factors about the players' available actions and the details of the equilibrium selection process. Below, we assume that D>0, and compare the costs and benefits of four broad methods for choosing an equilibrium. But first, this section explains why the payoffs in Figure 1 can be a sensible way to model the choice of compatibility standards, particularly in the Information and Communications technology (ICT) sector.

The benefits of compatibility (C-B in Figure 1) come in two flavors: horizontal and vertical. *Horizontal compatibility* is the ability to share complements across multiple platforms, and we call a platform horizontally open if its installed base of complements can be easily accessed from rival systems. Many parts of the Internet are in this sense horizontally open. For example, web pages can be displayed on competing web browsers, and rival instant messenger programs allow users to chat. Video game consoles and proprietary operating systems, such as Microsoft Windows, by contrast, are horizontally closed: absent further action (such as "porting"), an application written for one is not usable on others.

These distinctions can be nuanced. For example, what if a platform's set of complements is readily available to users of rival platforms, but at an additional charge, as with many banks' ATM networks? Similarly, Microsoft may have choices (such as the degree of support offered to cross-platform tools like Java) that affect, but do not fully determine, the speed and extent to which complements for Windows become available on other platforms.

Benefits of horizontal compatibility include the ability to communicate with a larger installed base (direct network effects) and positive feedback between the size of an installed base and the supply of complementary goods (indirect network effects). Katz and Shapiro (1985) analyzed oligopoly with firm-specific demand-side increasing returns. A more recent literature on many-sided platforms (e.g. Rochet and Tirole 2003; Parker and VanAlstyne 2005; Weyl 2010) extends the analysis of indirect network effects by allowing externalities and access prices to vary across different user groups.[2]

---

[2] See David and Greenstein (1990) or Shapiro and Varian (1998) for a review of the early literature on network effects, and Rysman (2009) for a review of the nascent literature on two-sided markets.

Vertical compatibility is the ability of those other than the platform sponsor to supply complements for the system. We call a platform vertically open if independent firms can supply complements without obtaining a platform leader's permission.[3] For example, the Hush-a-Phone case (238 F.2d 266, 1956), and the FCC's later *Carterfone* decision (13 F.C.C.2d 420) opened the U.S. telephone network to independently supplied attachments such as faxes, modems and answering machines. Many computing platforms, including Microsoft Windows, use vertical openness to attract independent software developers. Like horizontal openness, vertical openness can be a matter of degree rather than a sharp distinction. For instance, a platform leader may offer technically liberal access policies but charge access fees.

Vertical compatibility produces several types of benefits. There are benefits from increased variety when vertical compatibility allows users to "mix and match" components (Matutes and Regibeau 1988). Vertical openness also can reduce the cost of entry, strengthening competition in complementary markets. Finally, vertical compatibility leads to a "modular" system architecture and division of innovative labor. Isolating a module that is likely to experience a sustained trajectory of improvements allows other components to take advantage of performance gains while protecting them from the cost of redesign. And when the locus of demand or the value of complementary innovations is highly uncertain, modularity and vertical openness facilitate simultaneous design experiments (Bresnahan and Greenstein 1999; Baldwin and Clark 2000).

The benefits of horizontal or vertical compatibility are often broadly shared but need not be symmetric: there can also be private benefits of having a preferred technology become the industry standard. Such private benefits, labeled D in Figure 1, often lead to conflict and coordination difficulties in the search for compatibility.

One important source of conflict is the presence of an installed base. Upgrading an installed base can be costly, and firms typically favor standards that preserve their investments in existing designs. Moreover, platform leaders with a large installed base will favor designs that preserve or increase switching costs, while prospective entrants push to reduce them. For example, in its U.S. antitrust case, Microsoft was convicted of using illegal tactics to prevent Windows users, developers and OEMs from migrating to the independent standards embodied in the Netscape browser and Java programming language.

[3] Distinguishing between horizontal and vertical compatibility may help illuminate the often murky concept of open standards. Cargill (1994) suggests that the term `open' has become "an icon to conveniently represent all that is good about computing," so when conflicts emerge, all sides claim support of open standards. End-users typically define "open" in horizontal terms, since they seek a commitment to future competition at the platform level. Platform leaders typically emphasize vertical compatibility, which grants access to (but not control over) proprietary technology. Meanwhile, standards mavens call a technology open if it has been endorsed by an accredited SSO, and open-source advocates focus on free access to the underlying code.

Design leads are another source of conflict. Short ICT product life cycles leave firms a limited window of opportunity to capitalize on the demand unleashed by a new standard, and first-mover advantages can be important. Thus, firms may try to block or delay a new standard if rivals have a significant lead at implementation. DeLacy et al (2006) describe such efforts in the context of Wi-Fi standards development.

In some cases, there is conflict over the location of module boundaries, or what engineers call the "protocol stack." Since compatibility often promotes entry and competition, firms typically prefer to standardize components that complement their proprietary technology, but leave room for differentiation in areas where they have a technical edge. For example, Henderson (2003) describes how the networking technology start-up Ember allegedly joined several SSOs to prevent new standards from impinging on its core technology.

Conflicts can also emerge when firms own intellectual property rights in a proposed standard, which they hope to license to implementers, or use as leverage in future negotiations. Lerner, Strojwas and Tirole (2003) show that nearly all "modern" patent pools are linked to compatibility standards, and Simcoe (2007) documents a rapid increase in intellectual property disclosures in the formal standard setting process. While data on licensing are scant, Simcoe, Graham and Feldman (2009) show that patents disclosed in the formal standards process have an unusually high litigation rate.

Finally, conflicting interests can amplify technological uncertainty. In particular, when technical performance is hard to measure, firms and users will grow more skeptical of statements from self-interested participants about the quality of their favored design.

3. Four Paths to Compatibility

Given this mix of conflict, common interest and incomplete information, choosing compatibility standards can be a messy process. This section considers the performance of four paths to compatibility – standards wars, SSOs, dictators and converters – in terms of the probability of achieving compatibility, the expected time and resource costs, and the implications for *ex post* competition and innovation. We find that economic theory helps articulate some of the complex trade-offs among these paths, but there is little systematic evidence.

3.1 Standards Wars

Standards wars can be sponsored or unsponsored; for brevity we focus here on the sponsored variety, in which proponents of alternative technologies seek to preempt one another in the marketplace, each hoping that decentralized adoption will lead to their own solution becoming a *de facto* standard through positive feedback and increasing returns. Standards wars have broken out over video formats, modem protocols, Internet browsers, and transmission standards for electricity and cellular radio. These wars can be intense when horizontally incompatible platforms compete for a market with strong network effects, which they expect to tip towards a single winner who will likely acquire market power. Much has been written about the tactics and outcomes in such wars, and we do not attempt to be comprehensive here, only to remind the reader of some of the dynamics.[4]

Standards wars often involve a race to acquire early adopters and efforts to manipulate user expectations, as described in Besen and Farrell (1994) or Shapiro and Varian (1998). Pre-emption is one strategy for building an early lead in an adoption race. Another strategy is to aggressively court early adopters with marketing, promotions and pricing. Firms may also work to influence users' expectations regarding the likely winner, since these beliefs may be self-fulfilling.[5]

Firms that fall behind in a race for early adopters or expectations may use backward compatibility or bundling to catch up. Backward compatibility jump-starts the supply of complements for a new platform. For instance, many video game platforms can play games written for older consoles sold by the same firm. Bundling promotes the adoption of new standards by linking them to existing technology upgrades. For example, Sony bundled a Blu-ray disc player with the Playstation game console to promote that video format over HD-DVD, and Bresnahan and Yin (2007) argue that Microsoft took advantage of the Windows upgrade cycle to overtake Netscape in the browser wars.

Given the range of tactics used in a standards war, does decentralized technology adoption provide an attractive route to coordination? One social cost is that it will often lead to the emergence of a horizontally closed platform. While one might question the direction of causality (perhaps intractable conflicts over horizontal inter-operability lead to standards wars), alternative paths to coordination may lead to greater *ex post* competition and reduce the risk of stranded investments.

The economic logic of standards wars seems consistent with concerns that markets may "tip" prematurely and/or towards an inferior solution. While many cite the QWERTY keyboard layout as an example (e.g. David 1990), Liebowitz and Margolis (1990) dispute the empirical evidence, and suggest that markets will typically coordinate on the best available technology, as long as the benefits of changing platforms outweigh any switching costs. It is difficult to find natural experiments that might resolve this debate, e.g. by randomly assigning an early lead in settings where there are clear differences in platform quality. But even if standards wars

---

[4] Shapiro and Varian (1998) provide many other examples, and West (2009) contains a lengthy list of standards wars. Farrell and Klemperer (2007) review the economic theory.

[5] Farrell and Saloner (1986) model sequential technology adoption with network effects and show how outcomes may depend on users' initial beliefs. The novel StartUp (Kaplan, 1986 Ch. 9) provides an entertaining account of the battle for expectations, and the strategic use of backwards compatibility, in pen-based computer operating systems.

typically "get it right" in terms of selecting for quality, coordination problems may affect the timing of standards adoption.[6]

Optimists argue that standards wars are speedy, since participants have strong incentives to race for early adopters, and that fierce *ex ante* competition offsets any social cost of *ex post* incompatibility. But competition for early adopters does not always take the form of creating and transferring surplus, and its benefits must be weighed against the costs of stranded investments in a losing platform. Moreover, the uncertainty created by a standards war may cause forward-looking users, who fear choosing the losing platform, to delay commitments until the battle is resolved. For example, Dranove and Gandal (2003) find that preannouncement of the DIVX format temporarily slowed the adoption of DVD. Augeau, Rysman and Greenstein (2006) suggest that the standards war in 56K modems also delayed consumer adoption.

When it is costly to fight a standards war, participants may seek an escape route, such as some type of truce.[7] For example, the 56K modem standards war ended in adoption of a compromise protocol incorporating elements of both technologies. The battle between CDMA and TDMA cellular phone technology ended in a duopoly stalemate, with each standard capturing a significant share of the global market.

Ironically, these escape routes and stalemates illustrate a final strength of decentralized adoption as a path to compatibility: it can reveal that network effects are weak, or that technologies initially perceived as competing standards can ultimately coexist by serving different applications. For example, Bluetooth (IEEE 802.15) was conceived as a home networking standard, but ceded that market to Wi-Fi (IEEE 802.11) and is now widely used in short-range low-power devices, such as wireless headsets, keyboards and remote controls. Similarly, the plethora of digital image formats (JPEG, GIF, TIFF, PNG, BMP, etc.) reflect trade-offs between image-quality and compression, as well as compatibility with specific devices. Since "war" is a poor metaphor for the process of matching differentiated technology to niche markets, Updegrove (2007) has proposed the alternative label of "standards swarms" for settings where network effects are weak relative to the demand for variety.

3.2 Standard Setting Organizations

One alternative to standards wars is for interested parties to try and coordinate through negotiation. This process is often called formal or *de jure* standard setting, and typically occurs within consensus Standard Setting Organizations (SSOs).

---

[6] Cabral and Kretschmer (2007) even suggest that when tipping towards an inferior technology would be very costly, optimal government policy may be to *prolong* a standards war so participants can gather more information.

[7] Interestingly, many of the well-known standards wars that do result in a "fight to the death" involve media formats.

There are hundreds of SSOs, and many of these non-profit institutions develop standards for safety and performance measurement, as well as product compatibility.[8] We use a broad definition of SSO that includes globally recognized "big I" standard setters, such as ITU and ISO; private consortia that manage a particular platform, such as the IETF and W3C; and smaller consortia that focus on a particular technology, such as the USB Forum or the Blu-ray Disc Association.[9] This definition could even be stretched to include collaborative product-development groups, such as open-source software communities. While the largest SSOs have hundreds of sub-committees and maintain thousands of specifications, small consortia can resemble joint ventures, wherein a select group of firms develop and cross-license a single protocol under a so-called promoter-adopter agreement.

Standards practitioners typically distinguish between consortia and "accredited" Standards Developing Organizations (SDOs). SDOs sometimes receive preferential treatment in trade, government purchasing, and perhaps antitrust in return for adhering to best practices established by a national standards agency, such as the American National Standards Institute (ANSI).[10] Table 1 hints at the size and scope of formal standard-setting in the United States by counting entries in the 2006 ANSI catalog of American National Standards and listing the twenty largest ANSI-accredited SDOs.[11]

INSERT TABLE 1 ABOUT HERE

SSOs use a consensus process to reach decisions. Though definitions vary, consensus typically implies support from a substantial majority of participants. For

---

[8] A list of roughly 550 SSOs is available at www.consortiuminfo.org. Cargill (2002) and the Intellectual Property Owners Association (2009) suggest classification schemes.

[9] These acronyms stand for International Telecommunications Union (ITU), International Organization for Standards (ISO), Internet Engineering Task Force (IETF), and World Wide Web Consortium (W3C). For ICT standards, ISO and the International Electrotechnical Commission (IEC) collaborate through a group called the Joint Technical Committee (JTC 1). Murphy and Yates (2009) describe the relationship between these national standards bodies and the global standards system administered by ISO.

[10] Annex 1 of the World Trade Organization's Technical Barriers to Trade Agreement makes explicit reference to the ISO/IEC Guidelines for SDO procedure. In the United States, OMB Circular A-119 gives preference to SDOs in federal government purchasing, and the Standards Development Act of 2004 (HR 1086) grants certain antitrust exemptions. Speeches by Majoras (2005) and Varney (2010), and also the European Commission (2010) antitrust guidelines on horizontal co-operation provide some assurance to SSOs regarding open discussion of royalty rates.

[11] Compatibility standards make up roughly 43 percent of the total stock of American National Standards, with much of the other half related to performance measurement and safety. Thus the ICT sector's share of standards production exceeds its share of GDP, and even patenting. One explanation is that information technology is, by design, uniquely modular, so the ratio of standards to products is high. For example, Biddle et al (2010) estimated that a typical laptop implements between 250 and 500 different compatibility standards.

example, most accredited SDOs require a super-majority vote and a formal response to any "good faith" objections before approving a new standard. Since SSOs typically lack enforcement power, this screening process may serve as a signal of members' intentions to adopt a standard, or an effort to sway the market's beliefs. Rysman and Simcoe (2008) provide some empirical evidence that SSOs' non-binding endorsements can promote technology diffusion by studying citation rates for U.S. patents disclosed in the standard-setting process, and showing that an SSO endorsement leads to a measurable increase in forward citations.

Beyond using a loosely defined consensus process and relying on persuasion and network effects to enforce their standards, SSOs' internal rules and organization vary widely. Some are open to any interested participant, while others charge high fees and limit membership to a select group of firms. Some SSOs have a completely transparent process, while others reveal little information. Some SSOs require members to grant a royalty-free license to any intellectual property contained in a standard, while others are closely aligned with royalty-bearing patent pools. There has been little empirical research on the internal organization of SSOs, but Lemley (2002) and Chiao, Lerner and Tirole (2007) examine variation in SSOs' intellectual property rights policies.

Given SSOs' heterogeneity, what can we say about the costs and benefits of the consensus process as a path to coordination? Since SSOs encourage explicit comparisons and often have an engineering culture that emphasizes the role of technical quality, there is some reason to expect higher-quality standards than would emerge from a standards war or an uninformed choice among competing technologies. This prediction appears in the stochastic bargaining model of Simcoe (2010), as well as the war-of-attrition model of Farrell and Simcoe (2009), where SSOs provide a quality-screening mechanism.

But technical evaluation and screening for quality can impose lengthy delays, especially when the consensus process gives participants the power to block proposed solutions. A survey by the National Research Council (1990) found that standards practitioners viewed delays as a major problem, and Cargill (2001) suggests that the opportunity costs of delayed standardization explain a broad shift from accredited SDOs towards less formal consortia. Farrell and Saloner (1988) develop a formal model to compare outcomes in a standards war (grab-the-dollar game) to an SSO (war of attrition). Their theory predicts a basic trade-off: the formal consensus process leads to coordination more often, while the standards war selects a winner more quickly.

SSOs have sought ways to limit deadlocks and lengthy delays. Some grant a particular party the power to break deadlocks, though such unilateral decisions could be viewed as a distinct route to compatibility (see below). Another approach is to start early in the life of a technology, before firms commit to alternative designs. Illustrating the impact of commitment on delays, Simcoe (2010) shows how delays at the IETF increased as the Internet matured into a commercial platform.

But early standardization also has downsides; in particular, private actors have little incentive to contribute technology if they see no commercial opportunity, so anticipatory standards rely heavily on participation from public sector institutions such as academia or government labs.

A third way to resolve deadlocks is to agree on partial or incomplete standards. Such standards often include "vendor specific options" to facilitate product differentiation. And SSO participants sometimes agree to a "framework" that does not achieve full compatibility, but standardizes those parts of an interface where compromise can be reached (thus lowering the *ex post* cost of achieving compatibility through converters).[12]

Finally, SSOs may work faster if competing interests are placed in separate forums, such as independent working groups within a large SSO or even independent consortia. Lerner and Tirole (2006) model forum shopping when there is free entry into certification, and show that technology sponsors will choose the friendliest possible SSO, subject to the constraint that certification sways user beliefs enough to induce adoption. This "competing forums" approach works well if there is demand for variety and converters are cheap. But if network effects are strong, forum shopping may produce escalating commitments in advance of a standards war. For example, the Blu-ray and HD-DVD camps each established an independent implementers' forum to promote their own video format.

Beyond providing a forum for negotiation and certification activities, SSOs are often a locus of collaborative research and development. Thus, one might ask whether selecting this path to coordination has significant implications for innovation?

Some forms of innovation within SSOs raise a public goods problem: incentives are weak if all firms have free access to improvements, especially in highly competitive industries. Weiss and Toyofuku (1996) gather evidence of free riding in 10BaseT standards development. Cabral and Salant (2008) study a model where standardization leads to free riding in R&D, and find that firms may favor incompatibility if it helps them sustain a high rate of innovation. Eisenmann (2008) suggests that SSOs often struggle with "architectural" innovations that span many component technologies, since it is difficult to coordinate the decisions of specialized firms with narrow interests in the outcomes of a particular working group or technical committee.

However, such problems need not prevent all innovation within SSOs. Firms often contribute proprietary technology to open platforms, indicating that the benefits of standardizing a preferred technology outweigh the temptation to free-ride in those cases. Where SSOs encourage horizontal openness, that should encourage

[12] The decision to adopt a framework or incorporate vendor-specific options into a standard may be observable, and hence amenable to empirical research, since the work-process and published output of many important SSOs (e.g. 3GPP and the IETF) are publicly accessible.

innovation in complementary markets by expanding the addressable market or installed base. And while standards can reduce the scope for horizontal differentiation in the market for a focal component, increased competition may stimulate the search for extensions and other "vertical" quality enhancements, as emphasized in Bresnahan's (2002) analysis of divided technical leadership in the personal computer industry and the quality-ladder model of Acemoglu et al (2010).

Finally, in horizontally closed platforms, SSOs may encourage innovation by enabling commitments to vertical openness.[13] In particular, when a platform leader controls some bottleneck resource, small entrants may fear higher access prices or other policy changes that would capture a share of their innovation rents. Platform leaders might solve this hold-up problem by using SSOs to commit to *ex post* competition (see generally Farrell and Gallini (1988)). For instance, Xerox researchers used an SSO to give away the Ethernet protocol, and Microsoft took the same strategy with ActiveX (Sirbu and Hughes 1986; Varian and Shapiro 1998, 254).

One important way SSOs address potential hold-up problems is by requiring firms to disclose essential patents, and to license them on reasonable and non-discriminatory (RAND) terms. These policies seek to prevent patent holders from demanding royalties that reflect coordination problems and the sunk costs of implementation, as opposed to the way that well-informed *ex ante* negotiation would reflect benefits of their technology over the next best solution.[14] Although the "reasonable" royalty requirement can be hard to enforce, and SSOs cannot protect implementers from non-participating firms, these intellectual property policies are nevertheless an important method for platform leaders to commit to vertical openness.

In summary, Standard Setting Organizations are a heterogeneous set of institutions linked by their use of the consensus process. This process emphasizes technical performance, and may select for high-quality standards, but can also produce lengthy delays when participants disagree. SSOs also provide a forum for collaborative innovation, and a way for platform leaders to commit to vertical openness in order to promote market entry and complementary innovation.

3.3 Imposing a Standard

A third path to coordination is for someone with sufficient clout to simply impose a standard. This dominant player might be a platform leader, a large customer or complementor, or a government agency. A potential advantage of coordination by fiat is speed. In particular, dictators can avoid or resolve deadlocks that emerge in both standards wars and SSOs. System-wide architectural transitions may also be easier when a *de facto* platform leader internalizes the benefits of a "big push" and is

[13] Furman and Stern (2006) and Murray and Stern (2007) study the impact of "vertical" open access policies on innovation outside of network industries.
[14] Farrell et al (2007) describe an extensive legal and economic literature on SSO IPR policies.

therefore willing to bear much of the cost. However, since dictators are not always benevolent or capable of spotting the best technology, *ex post* competition, innovation incentives and technical quality will often depend on who is in charge.

Platform leaders often dictate standards for vertical inter-operability. For example, AT&T historically set the rules for connecting to the US telephone network, and IBM has long defined the interfaces used in the market for plug-compatible mainframes. More recently, Apple has maintained tight control over new applications for its iPhone/iPad platform.

In principle, platform leaders should have an incentive to use their control over key interfaces so as to organize the supply of complements efficiently. However, fears that incumbent monopolists will block entry or hold-up complementary innovators often lead to calls for policy-makers to intervene in support of vertically open interfaces.[15]

Farrell and Weiser (2003) summarize arguments for and against mandatory vertical openness, and introduce the term ICE (Internalizing Complementary Externalities) to summarize the *laissez faire* position that a platform leader has incentives to organize the supply of complements efficiently. When ICE holds, a platform leader's choice of vertical openness is efficient; open interfaces promote entry and competition in complementary markets, while closed interfaces might better encourage coordination and systemic innovation. However, Farrell and Weiser note multiple exceptions to the ICE principle, making it difficult to discern the efficiency of a platform leader's vertical policies in practice. For example, a platform sponsor may inefficiently limit access if it faces regulated prices in its primary market; if control over complements is a key tool for price discrimination; if it has a large installed base; or if a supply of independent complements would strengthen a competing platform.[16]

In addition to platform leaders, large customers or complementers can act as *de facto* standard setters. For instance, Wal-Mart played an important role in the standardization for Radio Frequency Identification (RFID) chips by committing to a particular specification. Similarly, movie studios played a significant role in resolving the standards war between Blu-ray and HD-DVD. And in some cases, the

---

[15] Calls for mandatory vertical openness often produce fierce debates. For example, prior to the 1956 consent decree, IBM resisted publishing the technical specifications that would allow vendors to offer "plug compatible" mainframes and peripherals. More recent are the debates over "net neutrality" and ISPs' freedom to charge prices based on the quality-of-service provided to different web sites or Internet applications.

[16] Weyl (2010) offers an alternative price-theoretic analysis of a monopoly that controls access to both sides of a two-sided platform. In his model, the monopoly tariffs exhibit two types of deviation from perfectly competitive pricing: a "classical market power distortion" (which resembles a Lerner markup rule) and a "Spence (1975) distortion" whereby the monopolist internalizes the network benefits to the marginal, as opposed to the average, platform adopter.

pivotal "customer" is actually a user group, as when Cable Labs – a consortium of broadcasters – developed the DOCSIS protocol for cable modems.

The interests of large complementors and direct customers are often at least loosely aligned with those of end-users, to the extent that their own competitive positions are not threatened. Thus consumers may well benefit from choices made by those powerful players. However, even well-informed powerful players may find it useful to gather information within an SSO before making a decision. Farrell and Simcoe (2009) model this hybrid process, and find that it often outperforms both uninformed immediate random choice and an SSO-based screening process that lacks a dominant third-party.

Government is a third potential dictator of standards. In some cases, the government exerts influence as a large customer. For example, the US Office of Management and Budget Circular A-119 encourages government agencies to use voluntary consensus standards. And in response to requests from the European Union, Microsoft submitted its Open Office XML file formats to ISO. More controversially, governments may use regulatory authority to promote a standard. For example, the U.S. Federal Communication Commission coordinated a switch from analog (NTSC) to digital (ATSC) television broadcasting. Sometimes support for standards is even legislated, as in the 2009 stimulus package, which contains incentives for physicians to adopt standardized electronic medical records (but does not take a position on any specific technology).

In general, government involvement can be relatively uncontroversial when there are large gains from coordination and little scope for innovation or uncertainty about the relative merits of different solutions. For instance, it is useful to have standards for daylight-saving time and driving on the right side of the road. Government involvement may also be appropriate where private control of an interface would lead to extreme market power primarily because of severe coordination problems as opposed to differences in quality. But government intervention in highly technical standard-setting processes can pose problems including lack of expertise, regulatory capture, and lock-in on the government-supported standard.

3.4 Converters and Multi-homing

Converters, adapters, translators and multi-homing are ways to reduce the degree or cost of incompatibility. For example, computers use a wide variety of file formats to store audio and video, but most software can read several types of files. Econometricians use translation programs, such as Stat Transfer, to share data with users of different statistical software. Even the Internet's core networking protocols arguably function as a cross-platform converter: as long as all machines and networks run TCP/IP, it is possible to connect many different platforms and applications over a wide variety of physical network configurations.

One benefit of using converters to achieve compatibility is that no single party incurs the full costs of switching. Rather, everyone can choose their preferred system, but can also tap into another platform's supply of complements, albeit at a cost and perhaps with some degradation. Since translators need not work in both directions, development costs are typically incurred by the party who benefits, or by a third party who expects to profit by charging those who benefit. And converters can avert the long deadlocks that may occur in a standards war or an open-ended negotiation, since there is no need to agree in advance on a common standard: each platform simply publishes its own interface specifications and lets the other side build a converter (assuming unanimous support for the converter-based solution).

Sometimes users or complementers may join several platforms; such multi-homing can resemble a converter solution. For example, most retailers accept several payment card systems, so consumers can pick one and for the most part not risk being unable to transact. Corts and Lederman (2009) show that video game-developers increasingly multi-home, and argue that multi-platform content explains declining concentration in the console market over time. And instead of seeking a common standard for all computer cables, most machines provide a variety of sockets to accommodate different connectors such as USB, SCSI, HDMI and Ethernet. Multi-homing preserves platform variety and may align the costs and benefits of horizontal compatibility. However, dedicated converters or coordination on a single platform become more efficient as the costs of platform adoption increase.

Of course, multi-homing or converters cannot eliminate conflicting interests, and can open new possibilities for strategic behavior. For example, firms may seek an advantage by providing converters to access a rival's complements while attempting to isolate their own network. Atari tried this strategy by developing a converter to allow its users to play games written for the rival Nintendo platform. However, Nintendo was able to block Atari's efforts by asserting intellectual property based on an encryption chip embedded in each new game (Shapiro and Varian, 1998).

Firms may use one-way converters to create market power on either side of a vertical interface. MacKie-Mason and Netz (2007) suggest that Intel pursued this strategy by including a "host controller" in the USB 2.0 specification, and allowing peripheral devices to speak with the host-controller, but delaying the release of information about the link between the host-controller and Intel's chipsets and motherboards.

Converters can also favor a particular platform by degrading, rather than fully blocking, inter-operability. Many computer users will be familiar with the frustrations of document portability, even though most word processors and spreadsheets contain converters that read, and sometimes write, in the file formats used by rival software.

Finally, converters may work poorly for technical reasons. This may be particularly salient for vertical interfaces, since allowing designs to proliferate undercuts the benefits associated with modularity and specialization across components. For example, most operating systems do not provide a fully specified interface for third-party hardware (e.g. printers or keyboards), and the "device driver" software that acts as a translator is widely believed to be the most common cause of system failures (Ganapathi et al., 2006).

In summary, converters are attractive because they preserve flexibility for implementers. However, in a standards war, firms may work to block converters, as Atari did. Firms may also gain competitive advantage by using converters to manipulate a vertical interface. And even when there is little conflict, dedicated compatibility standards may dominate converters for heavily used interfaces, where performance and scalability are important.

4. Choosing a path

What determines which path to compatibility is followed, or attempted, in a particular case? When will that choice be efficient? While data on the origins of compatibility standards are scant, this section offers some remarks on the selection process.[17]

Choosing a path to compatibility can itself be a coordination problem, creating an element of circularity in analysis of this choice. We try to sidestep this logical dilemma by grouping platforms into two categories: those with a dominant platform leader, and shared platforms that default to either collective governance (SSOs) or splintering and standards wars. Eisenmann (2008) suggests that this distinction between shared and proprietary platforms emerges early in the technology life cycle, based on firms' strategic decisions about horizontal openness. In particular, he predicts that platform leaders will predominate in "winner-take-all" markets where network effects are strong (relative to the demand for variety), multi-homing is costly, and the fixed costs of creating a new platform are substantial.

This life-cycle perspective of platform governance is consistent with the intriguing (though unsystematic) observation that many technologies settle on a particular path to compatibility, even a specific agency, and adhere to it over time. For example, the ITU has managed international inter-operability of telecommunications networks since 1865, and JEDEC has been the dominant SSO for creating open standards for semiconductor inter-operability (particularly in memory chips) since 1968. Likewise, for products such as operating systems and video game consoles, proprietary platform leadership has been the dominant mode of coordination across several generations of technology.

[17] One exception to the paucity of data is a paper by Biddle et al (2010) that identifies 250 compatibility standards used in a typical laptop. The authors worked with Intel to estimate that 20 percent of these standards come from individual companies, 44 percent from consortia and 36 percent from accredited SDOs.

Nevertheless, there are several well-known cases of dominant firms losing *de facto* control over a platform. The most famous example is IBM and the personal computer architecture. Other examples include the demise of micro-computing incumbents like Digital Equipment; Google replacing AltaVista as the dominant search engine; Microsoft's well-documented struggles to adapt to the Internet; and the ongoing displacement of the Symbian cellular phone operating system by alternatives from Research in Motion (Blackberry), Apple (iPhone) and Google (Android). Bresnahan (2001) suggests that a key condition for such "epochal" shifts in platform leadership is disruptive technical change at adjacent layers of the larger system, since it is hard to displace a platform leader through direct horizontal competition when network effects are strong. While this observation certainly accords with the facts of well-known cases, it is not very amenable to formal testing given the infrequent nature of such major shifts.

4.1 Selection and efficiency

When there is a clear platform leader, the ICE principle suggests that leader will have an incentive to choose an efficient coordination process regarding vertical compatibility. For example, the platform leader might delegate standard-setting activities to an SSO when fears of hold-up impede complementary innovation, but impose a standard when SSO negotiations deadlock.

Unfortunately, the ICE principle is subject to many caveats, bringing back questions about whether a platform leader chooses a particular path for its efficiency or for other reasons such as its impact on *ex post* competition. For instance, Gawer and Henderson (2007) use Intel's decision to disseminate USB as an example of ICE, while MacKie-Mason and Netz (2007) argue that Intel manipulated USB 2.0 to gain a competitive advantage. Where one study emphasizes the initial decision to give up control over a technology, the other emphasizes the use of one-way converters to exclude competitors and gain lead-time advantages in complementary markets. These competing USB narratives highlight the difficulty of determining a platform leader's motives.

Without a platform leader, it is less clear why the private costs and benefits of choosing an efficient path to compatibility would be aligned. If firms are *ex ante* symmetric, and commit to a path before learning the merits of competing solutions, they would have an *ex ante* incentive to choose the efficient mechanism. But standard setting is typically voluntary, and firms do not commit to abide by consensus decisions. Thus, when asymmetries are present, or emerge over time, firms may deviate to a path that favors their individual interests. While these deviations from collective governance may lead to the "forking" of standards, they do not necessarily block the SSO path, and in some cases the remaining participants can still achieve converter-based compatibility.

Some observers suggest that this chaotic situation can deliver the virtues of both decentralized adoption and collective choice. For example, Greenstein (2009) argues that a proliferation of SSOs combined with widespread independent technical experimentation is a sign of "healthy standards competition" on the commercial Internet. This optimistic view emphasizes the virtues of "standards swarms." When network effects are weak (as the absence of a platform leader might sometimes suggest), and substantial market or technological uncertainty exists, decentralized choice can identify promising standards for a particular niche, with SSOs emerging to facilitate coordination as needed. Unfortunately, there is no guarantee that mixing decentralized adoption with SSOs captures the benefits and avoids the costs of either path in isolation. In particular, either path may lead to a stalemate, and when decentralized adoption is the outside option there is always a danger of stranded investments or selecting the wrong system.

A second optimistic argument holds that new ways to govern shared technology platforms will arise in response to market pressures and technological opportunities. For example, Cargill (2001) and Murphy and Yates (2009) claim that accredited SDOs lost market share to small consortia during the 1980s and 1990s because the SDOs' ponderous decision-making procedures were ill-matched to rapid ICT product lifecycles (see also Besen and Farrell 1991). Smaller and less formal organizations might work faster by relaxing the definition of consensus, taking advantage of new technologies for collaboration, and allowing competing factions to work in isolation from one another. Berners-Lee (1999) cites delays at the IETF as a primary motive for creating the World Wide Web Consortium (W3C), and Figure 2 shows that consortia are indeed on the rise. [18]

INSERT FIGURE 2 ABOUT HERE

While this evolutionary hypothesis is intriguing, it is not obvious that organizational experimentation and competition will evolve an efficient path to compatibility. Simcoe (2010) shows that consortia still experience coordination delays when participants have conflicting interests over commercially significant technology. And the proliferation of SSOs also increases the potential for forum shopping, as emphasized by Lerner and Tirole. We view competition between SSOs as a promising topic for further research.[19] At present, it remains unclear whether the current proliferation of organizational models for SSOs is the outcome of, or part of, an evolutionary process, or simply confusion regarding how best to organize a complex multi-lateral negotiation.

[18] Observing the slowdown at many consortia, Cargill suggests that they too will be supplanted, perhaps by the open-source software development model, or other bottom-up efforts to establish *de facto* standards.

[19] A parallel literature on voluntary certification programs, reviewed in Dranove and Jin (2010), may offer insights on competition between SSOs that can also be applied to compatibility standards. For instance, they cite several recent studies that examine the proliferation of competing "eco-labeling" initiatives (e.g. Energy Star versus LEED for construction or Sustainable Forest Initiative versus Forest Stewardship Council for lumber).

4.2 Hybrid paths

While markets, committees, converters, and dictators offer distinct paths to compatibility, they can sometimes be combined. For example, standards wars may be resolved through negotiations at an SSO, or the intervention of a dominant firm; and slow SSO negotiations may be accelerated by an agreement to use converters, or by evidence that the market is tipping towards a particular solution.

Farrell and Saloner (1988) model a hybrid coordination process that combines markets and committees. In their model, the hybrid path combines the virtues of standards wars and SSOs without realizing all of the costs. In particular, the market works faster than an SSO, while the committee reduces the chance of inefficient splintering. The IETF's informal motto of "rough consensus and running code" reflects a similar logic. By emphasizing "running code," the IETF signals that firms should not wait for every issue to be resolved within a committee, and that some level of experimentation is desirable. However, it remains important to achieve at least "rough consensus" before implementation.

Synergies of hybrid style can also occur between SSOs. Independent firms and small consortia often work to pre-establish a standard, before submitting it to an accredited SDOs for certification. For example, Sun Microsystems used ISO's Publicly Accessible Specification (PAS) process to certify the Java programming language and ODF document format (Cargill 1997). Similarly, Microsoft used ISO's fast-track procedures to standardize its Open Office XML document formats. As described above, platform leaders may value SDO certification if it provides a credible signal of vertical openness that attracts complementary innovators. However, critics claim that fast-track procedures can undermine the "due process" and "balance of interest" requirements which distinguish SDOs from consortia, leading users or complementers to adopt proprietary technology out of a false sense of security.

A second hybrid path to compatibility occurs when participants in a standards war use converters to fashion an escape route. For example, the 56K modem standards war was resolved by adopting a formal standard that contained elements of competing systems. Converters can also reduce the scope of conflicting interests within an SSO, especially when participants adopt a "framework" that falls short of full compatibility.

An alternative escape route (and third hybrid path) relies on a dictator to break deadlocks within an SSO. Farrell and Simcoe (2009) analyze a model of consensus standard setting as a war of attrition, in which a poorly informed but neutral third party can break deadlocks by imposing a standard. They find that this hybrid process will often (but not always) outperform an uninterrupted screening process, or an immediate uninformed choice. In practice, there are many examples of a dominant player intervening to accelerate a consensus process, such as the case of DOCSIS (cable modems) or electronic health records, both mentioned above.

Thus, informally, there are some reasons to hope that a standards system with many paths to compatibility will perform well. Platform leaders often have an incentive to choose the efficient path, and a greater variety of "pure" paths means more options to choose from. SSOs may evolve in response to market pressures and technological opportunities. And both theory and practical observation suggest that many paths to compatibility can be combined in complementary ways.

At this point in our understanding, however, any optimism should be very cautious. Various exceptions to the ICE principle show that platform leaders may weigh efficiency against *ex post* competition when choosing a path to compatibility. It is not clear when competition among SSOs will lead to more efficient institutions, as opposed to increased forum shopping and technology splintering. And while hybrid paths can work well, they highlight the complex welfare trade-offs among the probability of coordination, the costs of negotiation, and the implications for *ex post* competition and innovation.

5. Conclusions

Compatibility standards can emerge through market competition, negotiated consensus, converters or the actions of a dominant firm. These four paths to compatibility have different costs and benefits which depend on whether a particular standard promotes vertical or horizontal inter-operability; the presence of an installed base or proprietary complements; firms' sunk investments in alternative designs; and the distribution of intellectual property rights.

When choosing a path to compatibility, there are trade-offs between the probability of coordination, expected costs in time and resources, and the implications for *ex post* competition and innovation. There is an argument that a platform leader will internalize these costs and benefits and choose the socially efficient path to compatibility. But that argument has many exceptions. Others argue that decentralized experimentation with different technologies, loosely coordinated by a combination of markets and SSOs, will typically produce good outcomes. However, it is hard to predict how far competition among SSOs leads them toward optimal policies, or how reliably standards wars select the superior platform.

Amid these complex questions, there is certainly scope for beneficial government involvement, whether as a large end-user, a regulator, or a third-party with technical expertise. But direct government intervention in highly technical standard-setting processes can pose problems including lack of expertise, regulatory capture, and lock-in on government-supported standards.

Viewing the economic literature on compatibility standards in terms of our four broad paths also suggests several research opportunities. First, there is very little data on the relative market share of these alternative paths. Thus, it is unclear whether economists have focused on the most important or most common modes of organizing the search for compatibility, or merely the routes they find most interesting. Our impression is that standards wars and platform leaders have received more academic attention than have SSOs and converters. Possibly this is because the former paths are replete with opportunities for interestingly strategic, yet familiarly market-based, competitive strategies, while the latter options lead to less tractable or more foreign questions of social choice and bargaining.

A second topic for research is the selection of a path to compatibility, particularly in the early stages of a technology life cycle. Many studies assume either a standards war or a platform leader (who might delegate the choice of standards for vertical compatibility to an SSO). But we know little about how the rules for collective governance of a shared platform emerge or evolve over time. And there is not much research on forum shopping by technology sponsors, or the nature and effects of competition among SSOs. Developing a better understanding of how a particular path is chosen represents a crucial first step towards quantifying the cost-benefit tradeoffs across paths (unless the assignment is random), and adjudicating debates over the efficiency of the selection process.

Finally, there is an opportunity to examine interactions among the four paths to compatibility. Despite some first steps towards modeling “hybrid” paths, there is no general theory and very little empirical evidence on who chooses the mechanism(s) and how, or on whether the four paths tend to complement or interfere with one another.

REFERENCES

Acemoglu, D., G. Gancia, and F. Zilibotti (2010). "Competing Engines: of Growth: Innovation and Standardization." NBER Working Paper 15958 .

Arthur, W. Brian. 1989. "Competing Technologies, Increasing Returns, and Lock-In by Historical Events." Economic Journal, 97: 642-65.

Augereau, A., S. Greenstein and M. Rysman (2006). "Coordination versus Differentiation in a Standards War: 56K modems." Rand Journal of Economics, 34 (4): 889-911.

Baldwin, C.Y. and Clark, K.B. (2000). Design Rules. Vol. 1: The Power of Modularity. Cambridge, Massachusetts: MIT Press.

Bekkers, R., G. Duysters, et al. (2002). "Intellectual Property Rights, Strategic Technology Agreements and Market Structure: The case of GSM." Research Policy, 31: 1141-1161.

Berners-Lee, T. and M. Fischetti (1999). Weaving the Web: The original design and ultimate destiny of the World Wide Web by its inventor. San Francisco: HarperSanFrancisco.

Besen, S. M. and J. Farrell (1991). "The Role of the ITU in Standardization: Pre-Eminence, Impotence, or Rubber Stamp?" Telecommunications Policy, 15(4): 311-321.

Besen, S. M. and J. Farrell (1994). Choosing how to compete - strategies and tactics in standardization. Journal of Economic Perspectives, 8(2): 117–131.

Besen, S. M. and G. Saloner (1989). The Economics of Telecommunications Standards. Changing the Rules: Technological Change, International Competition, and Regulation in Telecommunications. R. Crandall and K. Flamm. Washington, Brookings: 177-220

Biddle, B., A. White and S. Woods (2010). "How Many Standards in a Laptop? (And Other Empirical Questions)" Available at SSRN: http://ssrn.com/abstract=1619440.

Boudreau, K. (2010). "Open Platform Strategies and Innovation: Granting Access versus Devolving Control. " Management Science, 56(10): 1849-1872.

Bresnahan, T. (2002). "The Economics of the Microsoft Case." Stanford Law and Economics Olin Working Paper No. 232. (Available at SSRN: http://ssrn.com/abstract=304701.)

Bresnahan, T. and S. Greenstein (1999). "Technological competition and the structure of the computer industry." Journal of Industrial Economics, 47(1): 1–40.

Bresnahan, T. and P-L Yin (2007). "Standard Setting in Markets: The Browser War," in Standards and Public Policy, Cambridge University Press 2007, Shane Greenstein and Victor Stango, editors.

Cabral, L. and T. Kretschmer (2007) "Standards battles and public policy." in Standards and Public Policy, Cambridge University Press 2007, Shane Greenstein and Victor Stango, editors.

Cabral, L. and D. Salant (2008). "Evolving technologies and standards regulation." Working Paper. (Available at SSRN: http://ssrn.com/abstract=1120862).

Cargill, C. (2002). "Intellectual property rights and Standards Setting Organizations: An Overview of Failed Evolution." (Available at www.ftc.gov/opp/intellect/020418cargill.pdf)

Cargill, C. (2001). Evolutionary pressures in standardization: Considerations on ANSI's national standards strategy. Testimony Before the U.S. House of Representatives Science Committee. (http://www.sun.com/software/standards/Testimony-Final-reformatted.pdf).

Cargill, C. F. (1989). Information Technology Standardization : Theory, Process, and Organizations. Bedford, MA, Digital Press.

Cargill, C. F. (1997). Open Systems Atandardization : A Business Approach. Upper Saddle River, NJ, Prentice Hall PTR.

Chiao, B., J. Lerner, and Tirole, J. (2007). "The Rules of Standard Setting Organizations: An Empirical Analysis." RAND Journal of Economics. 38(4): 905-930.

Corts, K. and M. Lederman (2009). "Software exclusivity and the scope of indirect network effects in the U.S. home video game market" International Journal of Industrial Organization, 27(2): 121-136.

David, P. A. and S. Greenstein (1990). "The Economics of Compatibility Standards: An Introduction to Recent Research." Economics of Innovation and New Technology, 1(1): 3-42.

David, P. (1988). "Clio and the Economics of QWERTY." American Economic Review, 75: 332-337.

DeLacey, B., K. Herman, D. Kiron and J. Lerner (2006) "Strategic Behavior in Standard-Setting Organizations." Harvard NOM Working Paper No. 903214.

Dranove, D. and N. Gandal (2003). "The DVD vs. DIVX Standard War: Empirical Evidence of Network Effects and Preannouncement Effects," The Journal of Economics and Management Strategy, 12(3):363-386.

Dranove, D. and G. Jin (2010). "Quality Disclosure and Certification: Theory and Practice." Journal of Economic Literature, 48(4): 935–63.

Eisenmann, T. and L. Barley (2006). Atheros Communications. Harvard Business School Case 806-093.

Eisenmann, T. (2008). "Managing Proprietary and Shared Platforms." California Management Review, 50(4).

Eisenmann, Thomas R., Geoffrey Parker and Marshall Van Alstyne. "Opening Platforms: When, How and Why?" Chap. 6 in Platforms, Markets and Innovation, edited by Annabelle Gawer. Cheltenham, UK and Northampton, Mass.: Edward Elgar Publishing, 2009, paperback ed.

European Commission (2010). "Guidelines on the applicability of Article 101 of the Treaty on the Functioning of the European Union to horizontal co-operation agreements." Available at http://ec.europa.eu/competition/consultations/2010_horizontals/guidelines_en.pdf

Farrell, J. and N. Gallini (1988). "Second-Sourcing as a Commitment: Monopoly Incentives to Attract Competition." The Quarterly Journal of Economics, 103(4): 673-94.

Farrell, J. and P. Weiser (2003). "Modularity, Vertical Integration, and Open Access Policies: Towards a Convergence of Antitrust and Regulation in the Internet Age." Harvard Journal of Law and Technology, (17)1: 85-135.

Farrell, J., J. Hayes, C. Shapiro, and T. Sullivan (2007). "Standard setting, patents and hold-up."

Antitrust Law Journal, 74: 603–670.

Farrell, J. and P. Klemperer (2007). "Coordination and lock-in: Competition with switching costs and network effects." In M. Armstrong and R. H. Porter (Eds.), Handbook of Industrial Organization, Volume 3, pp. 1967–2056. Elsevier.

Farrell, J. and T. Simcoe (2009). "Choosing the Rules for Consensus Standardization." Working Paper. Available at http://people.bu.edu/tsimcoe

Farrell, J. and G. Saloner (1988). "Coordination through Committees and Markets." Rand Journal of Economics, 19(2): 235-252.

Farrell, J. and C. Shapiro (1992). "Standard Setting in High-Definition Television." Brookings Papers on Economic Activity: 1-93.

Farrell, J. (2007) "Should competition policy favor compatibility?" in Shane Greenstein and Victor Stango, eds., Standards and Public Policy, Cambridge: Cambridge University Press, 2007, pp. 372-388.

Furman, J. and S. Stern (2006). "Climbing atop the shoulders of giants: The impact of institutions on cumulative research." NBER Working Paper No. 12523.

Gawer A. and R. Henderson (2007). "Platform Owner Entry and Innovation in Complementary Markets: Evidence from Intel," Journal of Economics & Management Strategy, 16(1): 1-34.

Gallagher, S. and J. West (2009). "Reconceptualizing and expanding the positive feedback network effects model: A case study," Journal of Engineering and Technology Management, 26(3): 131-147.

Ganapathi, A., V. Ganapathi and D. Patterson (2006). "Windows XP Kernel Crash Analysis." Proceedings of the 20th Large Installation System Administration Conference, pp. 149-159.

Greenstein, S. (2009), "Glimmers and Signs of Innovative Health in the Commercial Internet," Colorado High Technology Law Journal. forthcoming.

Henderson, R. and K. Clark (1990). "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms." Administrative Science Quarterly, 35(1): 9-30.

Henderson, R. (2003). Ember Corp.: Developing the Next Ubiquitous Networking Standard. Harvard Business School Case Number 9-703-448.

Intellectual Property Owners Association (2009). Standards Primer: An Overview of Standards Setting Bodies and Patent-Related Issues that Arise in the Context of Standards Setting Activities. Section 16. (standardslaw.org/seminar/class-2/excerpts-from-ipo-standards-primer/)

Katz, M. L. and C. Shapiro (1985). "Network externalities, competition and compatibility." American Economic Review, 75: 424–440.

Liebowitz , S. J. and S. Margolis (1990) "The Fable of the Keys," Journal of Law and Economics, 33(1): 1-25.

Lemley, M. (2002). "Intellectual Property Rights and Standard Setting Organizations." California Law Review, 90: 1889-1981.

Lerner, J. and J. Tirole (2006). "A model of forum shopping." American Economic Review, 96(4): 1091–1113

Lerner, J., J. Tirole and M. Strojwas (2003). "Cooperative Marketing Agreements Between Competitors: Evidence from Patent Pools," NBER Working Papers 9680.

Majoras, D. (2005). "Recognizing the Pro-competitive Potential of Royalty Discussions in Standard-Setting." Stanford University Standardization and the Law Conference. September 23, 2005. http://www.ftc.gov/speeches/majoras/050923stanford.pdf.

Matutes, C. and Regibeau, P. (1988). ""Mix and Match": Product Compatibility without Network Externalities," RAND Journal of Economics, 19(2): 221-234.

Mackie-Mason, J. and J. Netz (2007) "Manipulating interface standards as an anticompetitive strategy," in Standards and Public Policy, Cambridge University Press 2007, Shane Greenstein and Victor Stango, editors.

Murray, F. and S. Stern (2007). "Do formal intellectual property rights hinder the free flow of scientific knowledge? An empirical test of the anti-commons hypothesis." Journal of Economic Behavior and Organization, 63(4): 648–687.

Murphy C. and J. Yates (2009). The International Organization for Standardisation (ISO). Routledge.

Parker, G. and M. Van Alstyne (2005). "Two-Sided Network Effects: A Theory of Information Product Design." Management Science, 51(10): 1494-1504.

Rochet, J-C. and J. Tirole. (2003) "Platform Competition in Two-sided Markets" Journal of the European Economic Association, 1(4): 990-1029.

Russell, A. L. (2006). "Rough Consensus and Running Code and the Internet-OSI Standards War." IEEE Annals of the History of Computing, July-September, 48–61.

Rysman, M. (2009). "The Economics of Two-Sided Markets." Journal of Economic Perspectives, 23(3): 125–43.

Rysman, M. and T. Simcoe (2008). "Patents and the performance of voluntary standard setting organizations." Management Science, 54 (11): 1920–1934.

Shapiro, C. (2001). Navigating the patent thicket: Cross licenses, patent pools, and standard setting. In A. Jaffe, J. Lerner, and S. Stern (Eds.), Innovation Policy and the Economy, Volume 1, pp. 119–150. MIT Press.

Shapiro, C. and H. R. Varian (1998). Information Rules : A Strategic Guide to the Network Economy. Boston, Mass., Harvard Business School Press.

Simcoe, T. (2010). "Standard Setting Committees: Consensus Governance for Shared Technology Platforms." American Economic Review, forthcoming. (http://ssrn.com/abstract=899595).

Simcoe, T., S. J. Graham and M. Feldman. (2009) "Competing on Standards? Entrepreneurship, Intellectual Property and Platform Technologies." Journal of Economics and Management Strategy, 18(3): 775-816.

Simcoe, T (2007). “Explaining the Increase in Intellectual Property Disclosure.” in Standards Edge: The Golden Mean. Bolin Group.

Spence, M. (1975). “Monopoly, Quality, and Regulation.” Bell Journal of Economics, 6(2): 417–429.

Varney, C. A. (2010) “Promoting Innovation Through Patent and Antitrust Law and Policy,” Remarks prepared for join USPTO FTC Workshop on the Intersection of Patent Policy and Antitrust Policy. May 26, 2010. Available at http://www.justice.gov/atr/public/speeches/260101.htm

Weiss, M. and R. Toyofuku (1996). “Free-ridership in the standards-setting process: the case of 10BaseT.” StandardView 4 (4), 205–212.

Weiss, M. B. and M. Sirbu (1990). “Technological choice in voluntary standards committees: An empirical analysis.” Economics of Innovation and New Technology, 1(1): 111–134.

West, J. (2007) “The Economic Realities of Open Standards: Black, White and Many Shades of Gray,” in Shane Greenstein and Victor Stango, eds., Standards and Public Policy, Cambridge: Cambridge University Press, 2007, pp. 87-122.

Weyl G. (2010) "A Price Theory of Multi-Sided Platforms," American Economic Review, 100(4): 1642-1672.

TABLE 1: MAJOR ANSI ACCREDITED SSOs

Acronym	Standards	ICT	Full Name
INCITS	10,503	Y	International Committee for Information Technology Standards
ASTM	8,339	N	American Society for Testing and Materials
IEEE	7,873	Y	Institute of Electrical and Electronics Engineers
UL	7,469	N	Underwriters Laboratories
ASME	7,026	N	American Society of Mechanical Engineers
ANSI/TIA	4,760	Y	Telecommunications Industry Association
ANSI/T1	3,876	Y	ANSI Telecommunications Subcommittee
ANSI/ASHRAE	3,070	N	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AWS	2,517	N	American Welding Society
ANSI/NFPA	2,365	N	National Fire Protection Association
ANSI/EIA	2,011	Y	Electronic Industries Association
ANSI/SCTE	1,803	Y	Society of Cable Telecommunications Engineers
ANSI/AWWA	1,759	N	American Water Works Association
ANSI/AAMI	1,621	Y	American Association of Medical Imaging
ANSI/NSF	1,612	N	National Sanitation Foundation
ANSI/ANS	1,225	N	American Nuclear Society
ANSI/API	1,225	N	American Petroleum Institute
ANSI/X9	940	N	Financial Industry Standards
ANSI/IPC	891	Y	Association Connecting Electronics Industries
ANSI/ISA	872	Y	International Society of Automation
Total ICT	30,786	43%	

Notes: List of largest ANSI accredited Standards Developing Organizations based on a count of documents listed in the 2006 ANSI catalog of American National Standards. The "Standards" column shows the actual document count. The "ICT" column indicates the authors' judgment as to whether that organization's primary focus is creating compatibility standards.

FIGURE 1: COMPATIBILITY CHOICE AS A COORDINATION GAME

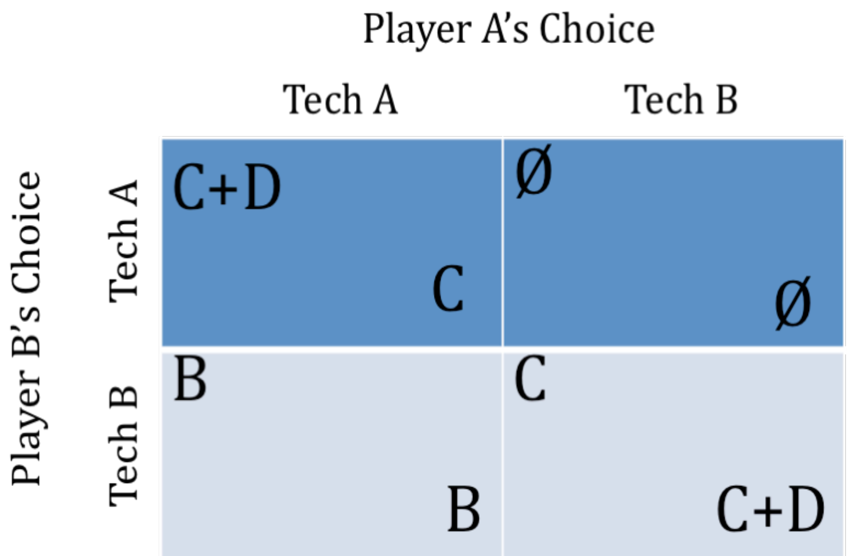
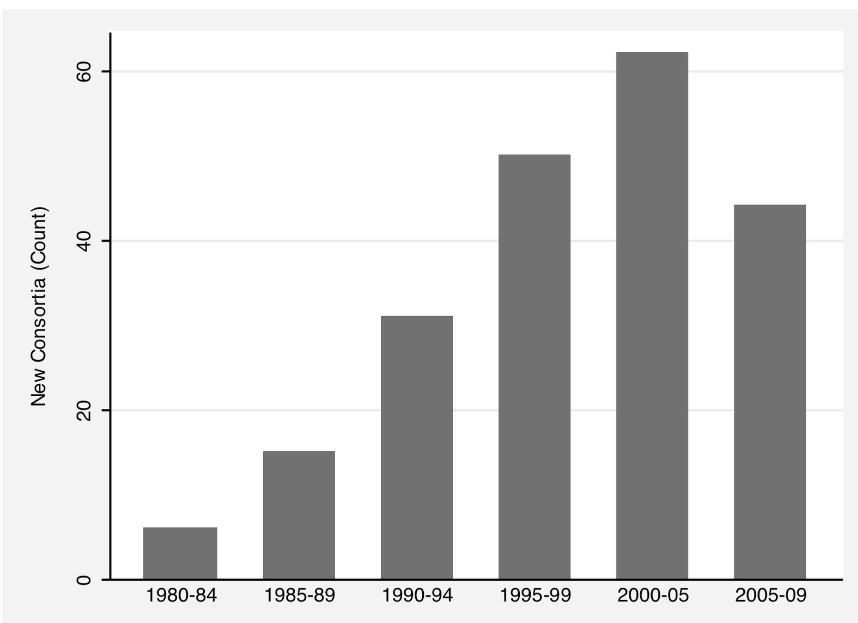


FIGURE 2: THE GROWTH OF CONSORTIA



Notes: Figure shows the cumulative number of new consortia founded during each five-year period, based on the authors' analysis of the list of ICT consortia maintained by Andrew Updegrove, and published at www.consortiuminfo.org.