Platform Competition in Telecommunications

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1.0 Introduction

In this chapter we consider the economics of platform competition in telecommunications. Platform competition occurs when different, sometimes incompatible, technologies compete to provide telecommunications services to end-users. Battles between competing technologies have been an important feature of telecommunications in the last twenty or so years. Examples of platform competition in telecommunications include wireless vs. wireline networks, competing wireless options, such as satellite vs. cellular, and, within cellular, different digital standards. Other examples include competing incompatible instant messaging offered by AOL, MSN, and Yahoo; and direct broadcast satellite vs. cable networks—to say nothing of the possibility of video delivered over the local phone network. A more broadly defined view of telecommunications widens motivating examples to include battles in consumer electronics between audio and video formats, as well as operating systems for personal computers.

These platform wars have become more significant, and more prominent, given the pace, nature, and magnitude of technological change in telecommunications, and information technologies, more generally. The ongoing convergence between telecommunications, entertainment, and computing is driven by fundamental changes and advances in the ability to manipulate information. All of these industries involve the manipulation, transmission, and/or reproduction of information, which in the broadest sense is anything that can be represented as (reduced to) a stream of binary code. The value of that manipulation depends often on how the information is gathered and distributed. The efficient gathering and distribution of information—perhaps after processing—typically occurs on a network. Competition between platforms in telecommunications, or technologies in information intensive industries typically involves more than just competition between differentiated products—in the interesting cases, and the concern of this chapter, it involves competition between technologies that are not only differentiated, but also are competing networks.

In this chapter we view platform competition through the lense of network economics to develop an understanding of the determinants of its outcome and adoption patterns by consumers. In Section 2 we define network industries and distinguish between types of networks. We introduce the concept of network effects and discuss how the presence of network effects affects demand for a platform. In this section, we also discuss settings in which network effects give rise to network externalities. In Section 3 we distinguish between standards wars, battles over compatibility, and cooperative standard setting leading to battles on the network—rather than between networks. Section 4 considers firm strategies in standards wars and raises the possibility that competition between incompatible technologies may not result in an efficient standard. Section 5 discusses battles for compatibility between dominant networks and competitors, while Section 6 discusses the economics of cooperative standard setting. Section 7 discusses the role of regulation in insuring compatibility (interconnection) and setting standards. Section 8 contains a number of case studies drawn from telecommunications that illustrate the principles of network competition discussed in the preceding sections.

2.0 Network Industries

The defining feature of network industries is that products consumed are systems of components: the ultimate "good" demanded is comprised of a group of complementary products that provide value when they are consumed together. It is most often the case that the components in and of themselves have very little, if any, value. In order to be of value they must typically be consumed as part of a system. For the complements to work together as a system requires standards to insure compatibility. In this context a "standard" refers to the set of technical specifications that enable compatibility between products.

It is common to distinguish between two different types of networks: direct networks and virtual, or indirect, networks. In the first, the system consists of similar products linked together in a network. In the second, the system consists of a unit of hardware and a unit of software.[3]

2.1 Direct Networks

Direct networks require horizontal compatibility, which is typically achieved through some sort of common standard across the products chosen by consumers who have joined the network. The archetype is a communication network where compatibility allows adopters[4] to communicate with each other. An adopter's link to the network has no value except to facilitate the transmission of information to, and from, other adopters. The value of a link to an adopter depends on the systems that can be created by combining their link with links of other adopters.

The classic example of a communication network is a telephone exchange. Consider a very simple example where n subscribers (adopters) are connected to a switch. The creation of a phone call from subscriber i to subscriber j involves combining two complements: subscriber *i's* link to the switch and subscriber *j's* link to the switch. Notice that in this example it is connection with the switch that insures compatibility with all other connected links. Two other examples of direct networks—where consumption benefits arise because of horizontal compatibility among adopters—are the communications standards built into facsimile machines and the Internet. Direct networks need not consist of, or depend on, cables in the ground, they may consist of individuals who adopt a similar word-processing program and derive benefits from being able to swap files with others (the horizontal compatibility here is the ability of the software to recognize and read files produced by others) or the network created by speakers of a common language (the horizontal compatibility here is the ability of both parties to comprehend and speak a common language).[5]

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[3] Modeling issues are briefly addressed in the appendix.
[4] We sometimes referred to consumers who join the network as subscribers or adopters.
[5] See Church and King (1993) and Gandal (2002a).

2.2 Virtual (Indirect) Networks

When the network is indirect, systems consist of one unit of hardware and one unit of software. The two components interact, or are combined, to provide consumption benefits: a unit of hardware or a variety of software typically have no, or relatively very little, stand-alone value. In the case of indirect networks what is important is vertical compatibility—compatibility between hardware and software. In the interesting cases, the unit of hardware is compatible with many different varieties of software.

Examples abound in consumer electronics: televisions and programming, compact disc players and compact discs, video game systems and video games, FM radios and FM radio stations, video- cassette recorders and prerecorded programming, digital music formats and digital music players, satellite radio and satellite radio channels. This "hardware- software" paradigm is not restricted to consumer electronics and the hardware need not literally be hardware. Other examples are operating systems (hardware) and application programs (software); credit cards (hardware) and the stores that accept them (software); natural gas powered vehicles (hardware) and natural gas filling stations (software); browsers (hardware) and websites (software); yellow pages (hardware) and yellow page listings (software); ATM cards (hardware) and ATM teller machines (software). In the last example, for instance, the value of an ATM card depends on the number of ATM machines at which it can be used. These examples suggest the identification of the software good as the component for which there are many possible varieties and the hardware good as the component for which there is a unit demand for a single variety. In the multiplicity of systems that can be created the hardware good does not change and it can be interpreted as the component which allows access to the software varieties.

2.3 Network Effects

Both types of networks are often characterized by a network effect. A network effect exists if the value of joining a network by buying compatible products is increasing in the number of other adopters who (ultimately) join the network by purchasing compatible products. With positive network effects, "bigger is better". In both cases the underlying source of the network benefit is the same: the larger the number of adopters the greater the possible number of systems (combinations of complementary components) an adopter can create.

Recall that a direct network consists of complements linked together to form a network. In this case, horizontal compatibility allows for interconnection of the product purchased by a consumer with that of others. In a direct network the number of systems that can be created by a subscriber equals the number of other adopters: in a telephone exchange with n consumers, subscriber i can create n-1 systems. The greater the total number of subscribers, the greater the number of systems.

When the network effect is indirect, consumption benefits do not depend directly on the size of the network (the total number of consumers who purchase compatible products) per se. Rather individuals care about the decisions of others because of the effect that has on the incentive for the provision of complementary products. Users of Macintosh computers are better off the greater the number of consumers who purchase Macs because the larger the number of Mac users the greater the demand for compatible software, which if matched by an appropriate supply response—entry by software firms—will lead to lower prices and a greater variety of software which makes all Mac users better off.

As in the direct network effects case, when there are indirect network effects consumers benefit from the adoption by others of compatible hardware because it allows them to consume a wider variety of systems. In this case consumption benefits flow from creating systems consisting of one unit of hardware and one unit of software where the unit of hardware is compatible with many different varieties of software. If consumers value variety, then they will demand multiple systems, each involving one unit of the hardware good and a different variety of software.[6] The advantage of more adopters of hardware to an existing subscriber arises if an increase in hardware adoption induces the

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[6] It is a rare individual indeed who listens to only one compact disc on their stereo, uses only one application program on their PC, or plays only one video game on their video game console.

production of more software varieties since existing adopters will then benefit from being able to create more "two-component" systems.

2.4 From Network Effects to Network Externalities

Both direct and indirect network effects can give rise to network externalities. An adoption externality arises when the network benefits of existing adopters increases when the size of the network increases, i.e., with the addition of another adopter. In both cases the source of benefit to inframarginal adopters from adoption at the margin is the creation of new systems by existing subscribers. The marginal adopter does not internalize the marginal external benefit when making their adoption decision, leading to underadoption.

In the case of a direct network, when an additional individual joins a network of n individuals, in addition to the n potential types of systems that are open to the new individual, the link of the new subscriber creates new systems for the n inframarginal, or existing, adopters. The addition of a new individual to an n individual network creates n new systems—combinations of complements that can be connected by existing subscribers to create a new good. It is this creation of new systems for existing subscribers/adopters that is the benefit to existing subscribers of network expansion.

As in the direct network effects case, when there are indirect network effects, consumers benefit from the adoption by others of compatible hardware because it allows them to consume a wider variety of systems. Inframarginal adopters of hardware benefit when there is an increase in hardware adoption if it induces an increase in the production of more software varieties, providing them with the option of creating more two-component systems.

The issue is that marginal consumers do not account for the effect that extending the hardware network will have on the variety of software, and thus the benefit inframarginal consumers receive from being able to consume additional software varieties. It is the number of *different* software varieties that is important, not the quantity (or price) of a particular software variety. That is, adoption externalities in the setting with indirect network effects are the result of *variety effects,* not price effects.[7] The manner in which inframarginal consumers benefit from indirect effects is identical to the manner in which they benefit when there are direct effects—the ability to create new systems of complementary products. Network externalities that arise in settings with indirect network effects have the same microfoundations as network externalities that rise in settings with direct network effects.

2.5 Implications for Consumer Demand

For products characterized by network effects the decision by consumers regarding which network to join—often referred to as the technological adoption decision of a consumer—will depend not only on relative product characteristics and prices, but also the expected size of the network. Moreover, the current size of the network, or its installed base, will often be used as a signal or indication to consumers of its future size. In the case of a direct network, the size of the installed base is usually measured by the number of adopters. In the case of indirect networks the size of the network can also be measured by the number of adopters of compatible hardware, but in many instances the relevant installed base is often the number of complementary software varieties available.

The role of the size of the existing installed base in determining the size of the network in the future arises because positive network effects give rise to positive feedback effects. Consumers will appreciate that a larger installed base today will make the network more attractive to adopters in the future, while the expectation that the network will be attractive to consumers in the future insures strong adoption in the present. These positive feedback effects create a strong tendency for "the strong to get stronger" in a virtuous cycle—the greater the installed base, the greater network benefits, the more

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[7] See Church, Gandal, and Krause (2003). They show that the requirements for indirect network effects to give rise to an adoption externality are three-fold: (i) increasing returns to scale in the production of software; (ii) free-entry into software; and (iii) consumer preferences for software variety. Under these circumstances the marginal adopter does not take into account the benefits that accrue to inframarginal adopters from the response of the software industry to an increase in hardware sales. When there are increasing returns to scale and free-entry into the production of differentiated software the key response to

attractive the network to adopters, the greater adoption, the greater the installed base, etc. When there are competing networks and one network experiences positive feedback effects it is often the case that its competitors experience negative feedback effects: "the weak get weaker" in a vicious cycle. The smaller the installed base, the smaller the network benefits, the less attractive the network, the greater the incentive to abandon the network, the smaller the installed base, etc.

Unlike economies of scale there is no reason for diseconomies from network effects. They may become small, but they will not be negative. Network effects are similar to demand side scale economies, but not identical since expectations matter. Consumption benefits are increasing not only in the number of consumers who adopt at time *t*—as with demand side scale economies—but also with the number of consumers who join the same network in the future.

2.6 Expectations and Competition between Networks

As we noted in the previous section, the value of joining a network when there are positive network effects depends on the ultimate size of the installed base of the network. This means that the expectations of consumers today regarding the growth of a network will be an important determinant of their adoption decision. And since a larger installed base today will contribute to growth in the future, the current size of the installed base will inform those expectations. The central role of expectations and their dependency on the current installed base has a number of important implications for competition in network markets.[8] These are (i) coordination problems, (ii) tipping/standardization, (iii) multiple equilibria; and (iv) lock-in.[9]

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an increase in hardware sales is an increase in software variety which benefits inframarginal consumers. These three conditions are both necessary and sufficient.

[8] The seminal contributions on competition in settings with network effects are a series of papers by Farrell and Saloner (1985, 1986a, 1986b) and Katz and Shapiro (1985, 1986). Katz and Shapiro (1994) and Besen and Farrell (1994) are excellent surveys on the economics of network industries. In what follows we draw liberally on all of these papers, following Church and Ware (1998). David and Greenstein (1990) provide a comprehensive survey of earlier work, while Farrell and Klemperer (2005) provide a detailed survey of more recent work. Gilbert (1992), Gandal (1995), Matutes and Regibeau (1996), Gandal (2002b), and Stango (2004) provide selective reviews of the literature.

Coordination Problems

Typically a consumer must invest in a connection (direct network) or hardware (indirect case) to join a network. If this investment is sunk, the potential for coordination problems arise. Consumers make these investments with the expectation that the network will grow and a certain level of network benefits will be realized. If the expected growth in the network is not realized, perhaps because it is abandoned by future generations of consumers, then its early adopters will be stranded on an "orphan" technology. In such a case the expected benefits associated with the sunk investment and membership on the network are not realized.

Uncertainty over being stranded makes consumers reluctant to join new networks whose installed base is small. The possibility of being stranded arises because of a coordination problem: consumers would be willing to join a new network if they knew that others were also willing to join, but because no one is presently on the network they do not believe that others are willing to join, and hence they, and others, do not. A similar coordination problem can affect the adoption prospects of an indirect network. Consumers would be willing to buy hardware if sufficient software variety was available or expected to be available. Software suppliers would find it profitable to support a hardware technology if it is adopted, but are reluctant to do so until consumers demonstrate that a market exists by adopting hardware. The coordination difficulties between consumers and suppliers of software—or more generally complementary products—is, for obvious reasons, known as the "chicken and egg" problem. The coordination problem in indirect networks is further complicated because hardware might not be introduced without the expectation of support from suppliers of complementary software. Firms will therefore have an incentive to try and minimize the risk to consumers of being stranded.

Standardization

Products characterized by network effects are highly susceptible to "tipping" or standardization. When a network market tips, consumers adopt or join only one

[9] Our discussion here follows Church and Ware (1998).

network, they do not support multiple competing networks/technologies. Competition between incompatible networks can easily result in the "winner taking all" where one technology becomes a *de facto* standard because all consumers adopt it. This occurs when network effects are particularly strong. When network effects are strong, if one system or technology can establish an initial edge in the size of its installed base, this provides an effective (and correct) signal to all consumers—present and future—that all consumers will also adopt this system. Small initial leads in market penetration can result in the creation of a very large sustained advantage and exclusive adoption. Firms whose technology is incompatible with their rivals in markets with strong network effects have an incentive to compete aggressively when their technology is introduced in order to establish an installed base advantage. Tipping and de facto standardization is more likely the stronger network effects are relative to the extent of consumer heterogeneity. If consumer preferences are relatively heterogeneous, then product differentiation considerations can trump network effects and multiple incompatible differentiated networks can coexist.

For instance, if consumers observe that video rental outlets typically stock predominantly video cassettes in the VHS format then they will tend to expect continued supply of VHS tapes in the future, providing them and others with incentives to purchase VHS compatible video cassette recorders. Consumers' expectations become self-fulfilling as video rental outlets —and eventually film studios—respond by reducing their library of Beta tapes and specialize in VHS. The standardization on the VHS format in North America is an example where product differentiation between the two standards was fairly minimal, but network effects were strong. This experience can be contrasted with the personal computer market where network effects have contributed to the dominance of the PC standard (Intel and Windows), but strong product differentiation has enabled Apple to carve out a niche in publishing and graphic design.

Multiple Equilibria

Multiple equilibria are possible, since the equilibrium outcome will depend on the expectations of consumers. For example, suppose there are two new competing technologies and that network effects are relatively strong. In these circumstances, depending on the expectations of consumers, the equilibrium outcome might be standardization on one of the new technologies or both technologies failing. The latter might be the case if consumers cannot coordinate on a standard and, due to concerns over stranding, play it safe by not adopting either technology. Firms will have an incentive to influence and coordinate the expectations of consumers.

Lock-In

Consumers can become locked in to a network because of switching costs. Two types of switching costs "lock-in" consumers to a network. When adoption entails a sunk cost and networks are incompatible, consumers that switch to another network will need to make an investment in the connection or hardware of the new network. Second, consumers might forgo network benefits if the installed base of the new network is not as large. This disadvantage might only be temporary, but it might be permanent if the installed base advantage of the incumbent network is expected to persist in the future. Lock-in means that consumers find it costly to switch to a competing network ex post and consequently, it makes them subject to opportunism by a network provider. The opportunism can take a number of forms including raising prices or lowering quality. In particular, promises by a network provider to expand its network by charging low prices or providing lots of inexpensive software in the future are not necessarily credible.

3.0 Battles for Standards, Compatibility and Adoption

Following Besen and Farrell (1994), it is useful to distinguish between four different situations. These are:

- a standards war between two or more incompatible standards (Section 4),
- battles over compatibility (Section 5),
- standard setting by voluntary agreement (Section 6) , and
- mandated standards by the state (Section 7).

In a standards war two or more incompatible systems compete against each other. Examples include: VHS vs. Beta, Visa vs. American Express, Linux vs. Windows, and

X-Box vs. PLAYSTATION. Standards wars typically arise between sponsors of closed systems. Sponsors have proprietary rights in their technology, often intellectual property rights, that prevents or limits competing firms from producing compatible products. The lack of competition on the network defines a closed system. Sponsors of a closed system wage a standards war in the hope of becoming a de facto standard, i.e., a monopolist.[10] The locus of competition will be on trying to create an installed base advantage and creating consumer expectations that its technology will win the standards war.

Battles over compatibility arise typically when the competition between incompatible standards has been resolved. The creation of a de facto standard means that competition between technologies/networks (inter-network competition) is not possible and instead the focus shifts to competition on the same network (intra-network competition). However, in order for there to be competition on the network, products of competing suppliers have to be compatible. The sponsor of the dominant network will have an incentive to limit and disrupt the ability of rival firms to produce compatible products, preferring to protect its profits and monopoly by maintaining incompatibility.

The last alternative is when firms that have developed, or in are in the process of developing, incompatible technologies forestall a standards war by agreeing to a common standard. Under a common standard all firms agree to produce compatible products, replacing inter-network competition for competition on a single network. Standard setting by agreement arises when firms forecast that competition on a single standard is likely to be more profitable than the expected profits from a standards war. In particular, firms will find it more profitable to agree to a common standard when consumers' expectations are fragmented or uncoordinated. In these circumstances a diversity of options with no clear winner may make consumers reluctant to adopt any of the competing technologies, and as a result the next generation of technology fails. Competing firms that have developed next generation networks can avoid this

[10] As we discuss below a system sponsor might open up its system to competition in order to mitigate lock-in and convince consumers that it will win the standards war. In this case it shares the monopoly with its intra-network competitors if its technology wins the standards war.

fragmentation by cooperatively agreeing to a standard. This can be done formally through national or industry standard setting bodies, or less formally when firms simply agree to a common standard. Common standards are implemented by firms agreeing on the technical specifications for interfaces to insure compatibility and making the technology embodied in the standard accessible to all.

A particular concern of standard setting bodies is to make sure that all of the technology embodied in a standard is licensed. Failure to do so can create a situation where a firm with an unlicensed technology embedded in the standard can end up in control of the standard, with considerable market power if the standard is adopted widely. For instance the code of practice covering intellectual property rights of the International Telecommunications Union-Telecommunications Standardization Sector (ITU-T) specifies that patent holders not willing to waive their patent rights or to negotiate licenses with reasonable terms on a non-discriminatory basis will not have their technology incorporated in a standard.[11]

4.0 Standards Wars

Firms in a standards war engage in a number of strategies aimed at credibly convincing consumers that their technology will become the de facto standard, or at the very least, have a larger installed base. Typically the strategies followed by firms do this by either (i) directly affecting the expectations of consumers or (ii) by exploiting the link between expectations and the size of the current installed base by making investments in the size of their installed base. The extent to which firms are willing to make investments to enhance the size of their network depends on their ability to capture the benefits from doing so, which in turn depends on being able to restrict access to their network by competitors.

4.1 Strategies in Standards Wars

[11] The ITU-T Patent Policy can be found online at "http://www.itu.int/ITU-T/dbase/patent/patent-policy.html".

Here we discuss a number of strategies that firms can, and have used, in order to influence the expectations of consumers and/or create a larger installed base.[12]

Penetration Pricing

Firms that adopt penetration pricing set an intertemporal pattern of pricing that promotes adoption of a product early in its life cycle in order to build up its installed base.[13] Firms following a penetration pricing strategy strategically lower their price, perhaps below marginal cost, in order to convince consumers to adopt their technology and build their installed base. The investment, through low prices, is recouped in the future when the firm's technology becomes a de facto standard or has a sufficient installed base that it provides consumers with considerable network benefits. These network benefits give it room to raise its prices to future adopters: its installed base gives it a competitive advantage over rival platforms, perhaps even deterring entry. The use of penetration pricing is a way for a firm to (partially) internalize the externality and transfer (through lower prices) some of the benefit to consumers today: subsidies to encourage adoption today are financed through higher prices in the future.

Advertising and Marketing

Promotional efforts will be aimed at providing information to shape the expectations of consumers regarding the relative size of the installed bases of competing networks. Credible information that a network is pulling ahead of its rivals—both in terms of its installed base or its current rate of adoption—can be particularly effective in changing or reinforcing the expectations of consumers.

Insurance

There are a variety of mechanisms through which firms can reduce the risk that consumers will be stranded. These included sophisticated pricing contracts where the ultimate price paid depends on the size of the network[14] or the firm retains ownership of

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[12] This section follows Church and Ware (1998).
[13] See Farrell and Saloner (1986b) and Katz and Shapiro (1986).
[14] See Dybvig and Spatt (1983) and Thum (1994).

the connection (direct) or hardware good (indirect) and recovers its cost through service fees or short term leases.[15] By reducing the risk of lock-in, insurance strategies make it easy for consumers to leave a network, thereby encouraging them to join.

Second Sourcing and Open Standards

Second sourcing occurs when firms license their products to other suppliers to create competition.[16] Like insurance schemes it is a means for firms to reduce the risk of lock-in, but rather than provide early adopters with protection from being stranded on a small network, second sourcing is a means to create an installed base and protect them from opportunism in the future if the technology is successfully established. When second sourcing creates competition, it signals to consumers that prices will be low now and in the future. This assures consumers today that the network will continue to grow.

A very aggressive form of second sourcing is the creation of an open standard. An open standard exists when its sponsor does not enforce its intellectual property rights. Under an open standard the technical specifications for compatibility are freely available to any firm for incorporation into their products. As a means to create competition among suppliers an open standard can be used when networks are either direct or indirect. When networks are direct, it creates competition among suppliers of substitute products that are horizontally compatible. In the case of indirect networks the open standard can encompass the hardware good, or more typically, it is used to promote third-party supply of complementary software. In both cases the strategy can be particularly effective since it creates competition on a standard today and if credible, it is a means to commit to lower prices, product differentiation, innovation on the standard, and variety (in the indirect network case) in the future, mitigating concerns over lock-in for early adopters and contributing to growth in the size of the network.

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[15] Katz and Shapiro (1994, p. 103).
[16] See Farrell and Gallini (1988) and Shepard (1987).

Signaling

A firm can also create credible incentives to continue to compete for adoptions in the future, thereby ensuring the growth of its network, and signal these incentives to adopters today by making valuable assets hostages.[17] It can do this by creating and maintaining a reputation for not stranding consumers by eliminating support and sales for a technology. Developing such a reputation can be very valuable if a firm produces multiple products or introduces new generations of technology. Alternatively, it may invest in large sunk expenditures whose recovery depends on growth in the size of the network. By doing so it sends the signal to adopters that it expects the network to grow, otherwise it would not have made the investments.

Product Preannouncements

A firm preannounces its product when it informs consumers about the future availability of its products.[18] If the announcement is credible—consumers actually believe that the firm will introduce its product as announced—the effect can be to induce consumers not to join a competing network, but to wait for the firm's product. They are likely to wait if the preannounced product is compatible with their existing network and/or its quality is greater than that of competing networks presently available. A preannouncement that induces consumers to wait limits the growth of the installed base of competing networks.

Investments in Complementary Software

In indirect networks, often the relevant installed base is complementary software, and hardware firms can make strategic investments to increase the supply of complementary software.[19] Hardware firms can do this by vertically integrating and supplying software and/or by subsidizing third-party suppliers, either by underwriting some of their costs or instituting support programs that lower the costs of third party-developers. In hardware/software industries what typically influences adoption decisions by consumers

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[17] Katz and Shapiro (1994, p. 104).
[18] See Farrell and Saloner (1986b) and Dranove and Gandal (2003).
[19] See Church and Gandal (1992; 1996; 2000) for discussions of strategic investment in software by hardware firms, and Whinston (1990), more generally, for a discussion of when tying software to hardware can lead to profitable monopolization of hardware and software.

is the *relative* number of software titles available, both today and in the future. Hence hardware firms can increase the relative size of their installed base by not only increasing software available for their system, but by also reducing the variety of software available for competing systems. This typically involves contractual restrictions on third-party software developers' freedom to provide software for other systems or foreclosure. Foreclosure involves acquisition of third-party software and elimination of the supply of software compatible with rival systems.

4.2 Standard Wars and Efficiency

Perhaps the central focus in the literature on standards wars has been on determining whether market processes, such as a standards war, can be relied upon to govern standard selection. There are two issues: (i) is standardization efficient and if so (ii) is the correct standard chosen. Whether standardization is efficient depends on a trade off between product diversity and network effects. Standardization maximizes the benefit from network effects but typically results in a reduction in variety for consumers. For standardization to be socially optimal requires network benefits to become more important as consumer preferences become more diverse. The tendency in the theoretical literature is for the equilibrium to be characterized by *insufficient standardization or too much variety.*[20]

For instance in Church and Gandal (1992) the bias against standardization arises from the incentive of software firms to reduce competition. Software firms can support one of two competing differentiated hardware systems. The decision of which system to support depends on expected profits and there are two effects associated with joining a network. An increase in software support increases demand for that hardware (the demand effect), which leads to an increase in software profits as the size of the network expands. On the other hand, an increase in the number of software varieties increases competition on that

[20] For the physical networks case, see Farrell and Saloner (1986a). For the virtual network case, see Chou and Shy (1990) and Church and Gandal (1992). All of these papers show that market forces often result in suboptimal standardization. Markovich (2001) examines the tradeoff between standardization and variety in a dynamic setting using numerical methods. Unlike the other papers in the literature, she finds that there can be excessive standardization in equilibrium.

network, which ceteris paribus, decreases profits (the competitive effect). Church and Gandal show that the competitive effect dominates the demand effect and the equilibrium is characterized by excess variety—both networks are supported by software firms—when consumers' valuation of software is relatively large (implying significant network effects) compared to the extent of hardware differentiation.

However, as Katz and Shapiro (1994) observe, an additional advantage of having multiple networks not considered formally in the theoretical literature is that multiple competing networks have an option value. Preserving multiple networks and selecting a standard after technical and demand uncertainty is resolved makes it more likely that the optimal standard will be implemented. Too early a choice may preclude a subsequent change to a superior standard:[21] total surplus would rise if there was a switch to an alternative.

Excess inertia occurs when a technically superior new standard is not able to replace an existing standard even if total surplus would ultimately be greater with a change in standards. Excess inertia might arise because of the advantage network effects provide for a prevailing platform with an installed base. Rather than evaluate their choices on the basis of price and quality, consumers will consider these and network benefits. An installed base advantage might be difficult for a new technology to overcome, deterring its entry and adoption, despite its technical superiority. Because of lock-in to the existing standard the transition to a socially superior technology is not made. Farrell and Saloner (1985) highlight the importance of coordination problems among consumers. Despite the technical superiority of a new technology, consumers will be reluctant to bear the costs and risk of adopting a new technology if they don't think that others will also adopt.[22] The difficulties associated with coordination are amplified when competing standards are introduced simultaneously.[23]

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[21] See Katz and Shapiro (1994, p. 106).
[22] Choi (1994) shows that uncertainty over the quality of technologies in the future has a similar effect. Early adopters have insufficient incentives to wait for the uncertainty to be resolved because they do not internalize a forward externality. A forward externality arises because when consumers today make their adoption decision before the quality of the standard is revealed rather than waiting, they deny consumers in

On the other hand, if the expectations and preferences of consumers are less "fragmented", it is more likely the case that a new technology is adopted too easily.[24] Insufficient friction arises when a change to a new technology is socially inefficient. This can be the case since new generations of consumers have socially excessive incentives to switch to a new superior technology: they do not take into account that they strand previous generations on the old standard when they switch, thereby limiting the growth of the network benefits of consumers on the old technology.[25]

The work of Katz and Shapiro (1986, 1992) suggests that strategic behavior by sponsored new technologies limits the ability of existing standards and contributes to *insufficient friction*. In particular, the theme of Katz and Shapiro's work is that sponsors of new superior technologies can limit the ability of existing standards to grow their network through penetration pricing. The ability of a firm to engage in penetration pricing

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the future the possibility of coordinating on a better standard. This forward externality is stronger than the backward externality—that adopters tomorrow do not consider the cost of stranding early adopters—leading to the result that there is a tendency for early adopters to move too soon, locking in an inefficient standard.

[23] Rysman (2003) considers explicitly a dynamic model with indirect network effects—where consumers can wait before adopting—the possibility that competing standards will result in a delay in adoption. His results are similar to Church and Gandal (1992): the equilibrium depends on the relative strength of the network and competitive effect. When the network effect is strong, the market tips and there is standardization earlier. When the competitive effect is relatively strong, however, the software firms support both of the competing hardware standards and consumers respond by delaying their adoption decision until one of the standards reaches a critical mass of software support, and then the market standardizes. The adoption delay equilibrium is not efficient. Postrel (1990) attributes, in part, the failure of quadraphonic sound in the 1970s to competing standards.

[24] Fragmented expectations can arise in the analysis of Farrell and Saloner (1985) because consumers' have incomplete information: they don't know the preferences of other adopters. Expectations are much less likely to be fragmented when consumers know the preferences of others and are able to coordinate on a Pareto Optimal alternative. A Pareto Optimal alternative is more likely to exist when consumers' preferences are relatively homogenous.

[25] See Katz and Shapiro (1986; 1992; 1994). Choi and Thum (1998) obtain the opposite result (excess inertia not insufficient friction) in a model very similar to Katz and Shapiro (1986) except that first generation consumers can wait and the new technology is not available for first generation consumers. The latter assumption negates the possibility of penetration pricing an insufficient friction. Choi and Thum (1998) find that consumers today who have the option of waiting for a superior technology tomorrow that is not available today tend to adopt the prevailing technology too often and too soon, rather than wait for the arrival of the superior technology. This is true when the technologies are supplied competitively. Sponsorship of the new technology exacerbates the tendency to excess inertia since early consumers know that if they wait they will face monopoly pricing from the sponsor of the new technology. The negative externality is that early generations of consumers by moving too early force later generations to either adopt an inferior technology to get network benefits or forgo network benefits for the superior technology.

depends on the extent to which they can finance below cost pricing today through higher prices in the future. Higher prices in the future are possible if the firm is able to develop an installed base advantage. However, the extent to which it can raise prices from an installed base advantage depends on the quality and price of competing alternatives in the future. As a result the technology expected to be superior tomorrow—either higher quality or lower cost—will have an advantage today, since by providing a more attractive option to consumers in the future *without* an installed base advantage, it is in a better position to limit the ability of the current technology sponsor to finance penetration pricing to attract consumers in the present than the current technology sponsor can limit it. The advantage that a sponsored technology has from penetration pricing gives it a large advantage over socially preferred, but non-proprietary existing standards, since without a sponsor the incentives to engage in penetration pricing are limited. The firm that lowers the price today to build up the installed base may not be able to benefit from the installed base in the future if it faces competition from other suppliers on the same standard. The differential ability of standard sponsors (existing versus new) to utilize penetration pricing contributes to "insufficient friction" or "excess momentum" as one incompatible technology replaces another.[26]

Excess momentum is less likely with indirect networks, especially if the installed base of complementary software is controlled by the sponsor of the existing hardware standard. In the case of indirect network effects it is easier for an incumbent to strategically manipulate the installed base than in the case of direct network effects. In the latter, it often takes time for consumers to arrive in the market and the installed base can only grow as consumers adopt through time. In the case of the former, hardware firms can invest in software/complementary software. Indeed Church and Gandal (1996) show that existing hardware sponsors have an incentive to strategically overinvest in software in order to deter entry of a competing standard, resulting in a bias in favor of the incumbent's standard. This bias results in either insufficient standardization (too much variety) or standardization on the wrong technology (the incumbent's). The result is an example of a raising rivals' cost strategy. It is profitable for an incumbent to strategically

[26] See Katz and Shapiro (1986; 1992).

invest in software varieties—given that it will be a monopolist—but the same level of investment in an installed base is not profitable for an entrant given that it will have to share the market with the incumbent.

5.0 Battles for Compatibility

Firms with an ownership interest in a platform that is dominant or has, through universal adoption, become a de facto standard have an incentive to restrict compatibility to preserve market power and profits. Because it is a de facto standard, the installed base of such a technology is often a sufficient barrier to entry to exclude entrants whose products are incompatible. Non-sponsors can only participate in the market if they gain access to the network, i.e., design compatible products. The issue of compatibility is not exogenous: either by design or exercise of property rights, incumbent firms may be able to block, or reduce, compatibility.

It is unlikely that the sponsor(s) of a network with a large installed base will grant compatibility. Doing so enhances intra-network competition—and in the absence of strong network competition—provides very little benefit to the system sponsor. Compatibility eliminates the installed base advantage of the incumbent, reducing its market power and profits. Dominant firms can attempt to frustrate and disrupt compatibility by denying compatibility and by making frequent and unannounced changes in product standards to introduce incompatibility.

5.1 Denying Compatibility

Depending on the circumstances, sponsors of standards can deny compatibility with competitors by (i) exercising their physical property rights to deny interconnection and therefore insure that competitors' products/services are not on their network; and (ii) asserting their intellectual property rights and refusing to license the standard (interface technology/knowledge required for compatibility) or, in the case of indirect networks, the installed base of software.

It is useful to distinguish between cases when changes in product standards make competitors incompatible and when they make complementary products supplied by third-parties incompatible. The economics of the former is relatively straightforward: creating incompatibility enhances or preserves the firm's market power by excluding competitors. The analysis of the latter is more difficult since in general a greater variety of complementary software (typically from independent software sources) increases the value of the standard and, ceteris paribus, the higher the price the monopolist supplier of the hardware can charge.[27]

However, two circumstances can be identified where the supplier of the standard has an incentive to restrict compatibility of complements. These are (i) closing up an open standard and (ii) intergenerational leverage.

5.2 Restricting Compatibility of Complementary Products

Closing An Open System

In these cases the dominant firm or system sponsor begins with an "open" system which allows second sourcing or third party provision of complementary products. In some cases second sourcing is in fact actively encouraged as the system sponsor recognizes that the credible commitment to low prices and a wide variety of complementary products it creates provides a competitive advantage in the market for the system or hardware good. Once, however, the standard is established or sales of the hardware good are of lesser importance—perhaps because the other standard has lost the standards war—the incentives of the system sponsor change. In the case in which its network becomes a standard it has an incentive to close up its system and engage in second degree price discrimination.[28] When it has lost the standards war—so that hardware sales are

[27] See Whinston (1990).

[28] Monopolization of complementary products through tying allows the system sponsor to price discriminate based on the intensity of use for complementary products. Sales of the complementary products indicate the intensity of use and if intensity of use reflects benefits, sales of complementary products can be used to price discriminate, i.e., extract more surplus from those who realize substantial benefit. This is done by raising the price of the complementary product above marginal cost (i.e. competitive levels). In order to raise the price of complementary goods, the system sponsor must exclude alternative suppliers of complementary products by tying. See Tirole (1988) or Church and Ware (2000) for additional details. Saloner (1990) and Greenstein (1990) discuss the dilemma that the incentive to

negligible—but there is still demand for complementary products from its (stranded) installed base, monopolization of complementary products will be profitable. Competitors can be excluded and complementary goods markets monopolized in two ways.

First, it can render third party complementary products incompatible, unnecessary, or inferior by manipulating interfaces. Second, a sponsor of a standard can exclude suppliers of complementary products by tying supply of its proprietary standard to supply of its complementary goods. This can be done either by: (i) contractual terms where the tying arrangement is explicit; (ii) de facto bundling where the proprietary standard is not available as a separate product, of which a special case is; (iii) a technological tie (the products are not physically available separately).

Whether it engages in changing its interface standards or tying the effect is to close up its system and monopolize the supply of complementary products. Not only can this result in a substantial lessening of competition in the market for complementary products, but it clearly reduces the incentive for innovation by suppliers of complementary products.

Intergenerational Leverage

This occurs when a dominant firm acquires control over the supply of its installed based of complementary products in order to deny access to competing network technologies. Control of the supply of complementary products—or being able to effectively insure that they are incompatible with other hardware technologies—provides the sponsor of the current standard an avenue to forestall entry of a better hardware technology. Through its control of the installed base of software the sponsor of the existing standard may be able to manage the transition to the next generation by insuring compatibility only between its

engage in second degree price discrimination presents for system sponsors. Second degree price discrimination and the supply of a wide variety of components depends on standardized interfaces. Raising the price of components above cost and standardized interfaces provides the incentive and opportunity for rival firms to enter and compete in the complementary product markets.

software and its hardware technology.[29] By enforcing incompatibility between its installed base of software and higher quality hardware introduced by rivals that reflects recent technical advances, the current monopolist may be able to monopolize the next generation of hardware. The effect is not only to maintain its monopoly, but to also reduce the incentives for innovation by rivals for its tying product—its monopoly hardware.[30]

6.0 Cooperative Standard Setting

Cooperative voluntary standard setting occurs when suppliers agree to compete "in the market" rather than "for the market" by making their products compatible. Compatibility is achieved by agreeing to a standard. In doing so, firms suppress competition between networks in favor of competition on a network. The locus of competition is not on building an installed base advantage, but instead price—and depending on the extent of the standard—product features. The more specific and detailed the standard, the less room there is for firms to engage in product differentiation and the more important price competition. Moreover, it is more likely the case that firms will follow a variety of product line strategies, with some that might have offered complete systems in a standards war, instead focusing on a subset of (compatible) components when there is a common standard.[31]

Cooperative standard setting requires agreement among potential suppliers. It cannot be imposed unilaterally. The incentive for competing sponsors of incompatible standards to develop and introduce a common standard depends on their expectations of the likely alternatives and their profits. The alternatives are (i) a standards war that results in de facto standardization; (ii) multiple competing differentiated networks (if network effects are not strong enough to trump the advantages of product differentiation); and (iii)

[29] The implicit assumption is that the new technology does not find it profitable to create its own installed base of software. See Church and Gandal (1996) and our earlier discussion in Section 4.0 for why this may be the case.
[30] For related formal analyses see Choi and Stefanadis (2001) and Carlton and Waldman (2002). See also Rubinfeld (1998).

fragmentation of adopter's expectations with the result that none of the competing technologies is viable.

If the likely outcome is understood by suppliers to be fragmentation of consumers' expectations when there are competing standards, then agreeing to reach a common standard will not be difficult. However, agreeing to set and adopt a common standard is not the same thing as reaching agreement on the details of the standard. Disagreement over the details of the standard can arise for a number of reasons, including (i) preference differences among consumers; (ii) preference differences among sponsors stemming from proprietary rights, first-mover or other experience advantages; (iii) uncertainty and consequently disagreement, over future developments in the industry; and (iv) asymmetries of information and strategic bargaining.[32]

It is often the case that the determination of a voluntary standard has attributes similar to that of the "battle of sexes game". Each firm would like to have standardization on its technology, but prefers standardization on the technology of a rival to none at all. Farrell and Saloner (1988) examine the incentives for firms to achieve coordination through voluntary standard setting (standardization committees) where the structure of firm payoffs are similar to that of the battle of the sexes and firms have the option of forgoing negotiations and starting a (possibly unsuccessful) standards war.[33]

A firm will be reluctant to agree to a common standard if its expected profits from a standards war exceed its expected profits from agreeing to, and competing on, a common

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[31] This point is made by Shapiro and Varian (1999, p. 233).
[32] See Besen and Farrell (1994, pp. 124-126) for a discussion of the commitments and concessions often made by firms when negotiating a standard.
[33] They use a simple model in which two firms prefer their own incompatible standard to that of a rival, but also prefer standardization to incompatibility. Belleflamme (2002) is an extension of Farrell and Saloner (1988) where players have to choose between an existing standard and a standard known to be superior in the future. Belleflamme compares two standard setting processes: unilateral adoption to create a bandwagon and negotiation. Unilateral adoption leads to excessive and early adoption of the existing standard, negotiation to excessive and late adoption of the evolving standard. However, if firms can choose the standard setting process, the outcome almost always maximizes the sum of payoffs, i.e., is efficient.

standard.[34] This will more likely be the case when (i) failure to standardize does not have a significant adverse affect on consumer adoption because of uncertainty and concerns over stranding; (ii) the firm is well positioned to win a battle of standards, perhaps because of its ability to easily implement the strategies discussed in Section 4.0 to increase its installed base and favorably influence consumers expectations; (iii) the firm has sufficient ability to "harvest" the monopoly rents associated with its technology becoming the standard (that is, it has sufficiently strong intellectual property rights and/or is able to follow the strategies discussed in Section 5.0 to restrict competition on its network); (iv) it has a sufficient competitive advantage vis-à-vis competitors that in winning the standards war, its profit dissipation is restricted; (v) competition on a standard will be particularly dissipative with respect to profits, perhaps because the products of firms will be relatively undifferentiated due to standardization.

In many industries, including telecommunications, there are established institutions which provide forums for the discussion and determination of industry standards.[35] For example, the International Telecommunications Union Telecommunication Standardization Sector (ITU-T) has 13 study groups which make recommendations on standards in all fields of telecommunications, ranging from the assignment of telephone numbers to protocols for data transmission. As of 2004 the ITU-T had more than 2700 recommendations in force. The standards set by the ITU-T are called recommendations because the ITU-T cannot force compliance. The value of interconnection between telecommunications networks, however, is a powerful incentive for firms to comply with its recommendations.

There are two attributes of formal standard setting bodies that are a source of both their strength and weakness. Formal standard setting bodies are typically open to all participants and work on consensus. The power of consensus is that it insures that

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[34] de Palma and Leruth (1996) present a formal model in which firms noncooperatively determine whether to compete with incompatible networks or instead both agree to a common standard and produce compatible products. Compatibility requires the cooperation of both firms and it will not be forthcoming if one of them has a high enough prior that they will dominate in a standards war.

standards are open and that any proprietary technology incorporated into a standard is available to all on "fair, reasonable, and nondiscriminatory" terms. Both their open nature and the inclusive process by which official standards are set often provide them with considerable credibility vis-à-vis consumers, encouraging adoption.

On the other hand, because of both of these "open" attributes the process of negotiating open standards can be very slow, ineffectual, and inflexible. The process is likely to be slow because any interested participants are welcome to participate and they will often have divergent interests. Firms will have an incentive to participate because the outcome of negotiations on standards will often be an important determinant of their profitability. Their interests will diverge because the competitive position of each firm ex post will depend on the details of the standard adopted.

Moreover, unless the decision of the standard setting body is adopted by (most) suppliers, the standard set will be irrelevant. An important determinant of the effectiveness of the standard is whether it is incentive compatible: Will firms party to the standard honor their commitment to compatibility? Modifications to a standard may not be timely, or even possible, due to high transaction costs associated with reaching consensus. As a result official standards are more likely to become irrelevant when market circumstances are subject to frequent change.

7.0 Mandated Standards

Another alternative to market mediated standards is the setting of standards by regulators. The presence of an official standard setting body with the power to impose standards, such as a regulator, distinguishes voluntary standard setting from mandated standards.[36]

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[35] See Shapiro and Varian (1999), Grindley (1995), Katz and Shapiro (1999), and Farrell and Saloner (1992) for more extensive discussion and references on formal standard setting.
[36] One of the few papers that explicitly models the behaviour of a regulator to impose a mandatory standard is Cabral and Kretschmer (2004). They examine how uncertainty over the preferences of consumers between competing standards affects when and which standard is adopted.

The factors underlying voluntary standard setting by firms discussed in the previous section are industry and firm profitability. However, the importance of adoption of a common standard for consumers in some industries may result in de jure standard setting by a regulator or other apparatus of the state. An important public policy issue arises when firms are unable, or unwilling, to reach an agreement on a common standard. Intervention in standard setting by the state is typically motivated by the presumption that a standards war in such circumstances is inefficient. The existence of a standards battle and the absence of a voluntary agreement on a common standard suggests that at least one sponsor of an incompatible technology believes that it is well positioned to win and profit from a standards war. Besen and Saloner (1989) suggest that these circumstances are when the private value of winning a standards war is high and network effects are significant.[37] If network effects are large then the impact of standardization on demand—both adoption and market size/growth—will likely be significant. And it is precisely in these circumstances when the costs of a standards war may make intervention preferable. The key benefit of mandated standardization is the creation of a credible standard which encourages adoption, avoiding the costs associated with a market process.

7.1 Advantages of Mandated Standards

There are a number of costs associated with a standards war. These costs may mean that it is preferable to instead have a mandated common standard.[38]

Failure to Standardize

Perhaps the most important cost that might arise from a standards war is that in the standards war a *de facto* standard is not established. As a consequence network benefits are not maximized. If the failure to standardize fragments the expectations of consumers sufficiently, then none of the competing technologies might be adopted. A mandated common standard would maximize network benefits.

[37] See also Grindley (1995) Chapter 3.

[38] For more detailed discussion see Rohlfs (2003), Shapiro and Varian (1999), and, especially, Grindley (1995). Our presentation in this and the next section follows Grindley.

Stranding

If there is a winner in the standards war, then some consumers and some producers of complementary products will be orphaned. Those consumers and producers who made sunk expenditures on losing standards will not realize the anticipated benefits from those expenditures. A common standard adopted early enough would have forestalled these type of mistakes by consumers and producers of complementary products.

Duplication of Development and Promotion Expenditures

Competing standards also entail duplication of development and promotion programs. To the extent that these expenditures are sunk, the expenditures of losers in the standards war will be economically wasteful. Moreover, given the nature of these expenditures and the winner takes all nature of the competition, it is difficult for firms to reduce the extent and risk of these expenditures through a staged introduction of their products.

Inefficient Standardization

As discussed in Section 4.0, the outcome of a standards war may not be efficient. The result could be standardization on the wrong technology or excessive standardization. In the later case welfare would be higher if a variety of standards were available. In the short-run this advantage arises because of the benefits of product differentiation: the greater the selection of products the less the costs from a mismatch between the preferences of consumers and the characteristics of products available. In the long-run the advantage of competing products extends to include competition in innovation.

Market Power

The winner of a standards war may be able to exercise considerable market power without concern regarding entry because of the barrier to entry created by its installed base. Moreover, its market power may be particularly enduring if it is able to frustrate attempts by entrants to produce compatible products, or it is able to use its present installed base to extend its monopoly to include the next generation of technology.[39]

7.2 Advantages of Market Standards

The costs associated with mandated standards arise because of the nature of the process. The process is likely to be inclusive and open, suggesting as with voluntary standards, that standard setting will be methodical, slow, and costly. Moreover, the process is made more difficult by the fact that the standard setting body will likely be (i) remote from the market; (ii) much less well informed than market participants; and (iii) have its own policy agenda. Its remoteness means that it is likely to have a focus on technical criteria rather than market acceptance. Because of asymmetries of information, firms typically know more about costs, quality, and potential technological progress than regulators providing firms with an opportunity to strategically influence regulators and making it difficult for regulators to set efficient standards. If the standard setting body takes into account other policy objectives besides choosing an efficient standard, the result could be a standard that is irrelevant, or one which does not have credibility with adopters. A danger with mandatory standard setting is that these considerations will result in setting a standard too early, i.e., setting a standard without relevant information that would be gained by waiting. Finally, as with any administrative process, rent-seeking behavior with its attendant inefficiencies, will be induced by the prospect of mandated standards.

There are also some benefits of using markets to determine standards which are lost when a standard is mandated. It is important to remember that strategic behavior designed to enhance a firm's installed base is only contemplated because the winning firm has property rights in its network and thus finds it profitable to attempt to internalize the network externality. If the network were non-proprietary—as in the case of a common mandated standard— then firms will have significantly less incentive to make investments in increasing the size of its installed base. As a result the coordination problems inherent in network industries may mean that no technology is successfully adopted or that the network size is substandard and consumers do not benefit as much as they could from network effects.

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[39] See the discussion in Section 5.0 *supra.*

In addition using the market to determine standards has other advantages relative to a mandated standard. These include that, relative to mandated standards, (i) the resolution of the standards war and determination of the standard is often quick and the standard definitive; (ii) quality and costs of competing standards is done post-development and any trade-off is evaluated in the market; (iii) depending on the outcome of the standards war, there is not necessarily the same loss in variety.

Hence, despite the costs associated with market determined standards, competition in the market is probably preferable to mandated standards in most cases—with two exceptions. The first is when network effects are significant and the presence of multiple competing standards suggests the strong possibility that fragmented expectations on the part of consumers will prevent adoption of a new, superior, technology. The second is more obvious and of considerable relevance to telecommunications as we discuss in the next section.

7.3 Mandated Standards in Telecommunications Networks

New networks and platforms are unlikely to compete successfully against the local networks of the incumbent local telephone company without regulatory intervention regarding interconnection. The reason is the installed based advantage of the incumbent carrier. In the absence of interconnection, it would be very difficult for a competing telecommunications provider to compete: call completion would only be possible if both parties subscribed to the same network. Consumers would be unlikely, in these circumstances, to unsubscribe from the incumbent network and subscribe to the network of either a new wireline network or a new platform such as wireless.

To counter this, virtually every regulator which has introduced competition has mandated and regulated the terms of interconnection between the existing local telecommunications network and the networks/platforms of new entrants. Regulators do so in order to eliminate the installed base advantage of the incumbents. Without mandatory interconnection—a form of standardization—competition in telecommunications would be a non-starter, whether it was from competing telecommunications networks or other platforms/technologies, e.g., wireless, cable, or voice over internet protocol (VOIP).[40]

8.0 Case Studies:

This section provides a number of case studies drawn from telecommunications and information services that illustrate the principles of network competition discussed in the previous sections.

8.1 Competition in the Mobile Cellular Industry

In most settings in which network effects are present, compatibility across platforms or its absence is a key determinant of the success or failure of a particular technology. In the case of wireless telecommunications, however, interconnection and the availability of the relevant infrastructure can be a substitute for compatibility. An individual subscribing to any one of the wireless technologies (analog, AMPS, CDMA, GSM, TDMA and iDEN) in the U.S. can make calls to and receive calls from someone else subscribing to any one of the other standards (or to and from the wireline network) as long as there is (i) interconnection between networks and (ii) the relevant infrastructure is in place. In the U.S. (and several other developed countries), interconnection has been achieved by standard interconnection protocols.

[40] See Noam (2002) for a discussion of the nature, history, rationale, and importance of interconnection policies in creating and sustaining competition in telecommunications. The issue of mandatory interconnection has similarities to the use of converters and adaptors to create compatibility between incompatible networks. For an examination of the effects of converters see Farrell and Saloner (1992) or Choi (1996). Farrell and Saloner show that converters can result in less compatibility and excessive variety of networks since the private costs of ignoring network benefits are mitigated by the converter ex post. Choi (1996) shows that the existence of converters can harm the adoption prospects of a new technology competing against an existing network with an installed base. The presence of converters reduces the risk and costs of being stranded, thereby encouraging consumers to adopt the prevailing standard and not the new technology. Choi also shows that this effect is welfare improving since it reduces the extent of insufficient friction. These results mirror Choi (1994) who finds that ex post standardization policy, standardization policy after first generation consumers have adopted a technology, encourages them to adopt an inferior technology, knowing that they will be protected from being stranded if it is efficient to standardize after they have adopted. The policy is ex ante inefficient if the harm from eliminating stranding in the future is less than the adverse effects of encouraging early adoption.

Hence, at first glance, competition within the wireless industry resembles competition within the market, rather than competition for the market, that is, competition between compatible technologies. Nevertheless, interconnection does not completely eliminate the importance of network effects in mobile telecommunications competition. This is because networks typically charge different prices for on-net and off-net calls.[41] (An on-net call is a call that originates and terminates on the same network, while an off-net call originates on one network and terminates on another network.) Typically on-net prices are lower than off-net prices. This creates what is sometimes referred to as tariff-mediated network effects.[42]

Lower on-net prices and the induced tariff-mediated network effects mean that standardization may occur on one platform, despite interconnection. Hence, competition in mobile networks embodies some aspects of competition between incompatible networks. A key difference between competition in "interconnected" telecommunications networks and other networks is that in a "variety" equilibrium, interconnection insures that all consumers can indeed call each other.

The mobile telecommunications industry also provides an opportunity to examine the benefits of standard setting vs. market competition.[43] Since 1994, Europe and North America have taken divergent approaches in the market for wireless for voice and data services. The European Community mandated a harmonized standard, GSM, in the second generation (2G) bands. In contrast, the North American approach has been to allow the market to decide, that is, operators have been free to choose among four digital wireless standards: CDMA/IS-95, GSM, TDMA and iDEN.[44] In the case of 3G, a standards war between Wideband CDMA (WCDMA) and CDMA2000 is in a nascent stage.

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[41] This is only relevant in calling party pays (CPP) systems which exist in most European countries. In the U.S. this issue does not arise.
[42] See Laffont, Rey and Tirole (1998a, 1998b).
[43] Funk and Methe (2001) provides an excellent overview of standards development in wireless and the role mandated standardization in a region/country played in creating an installed base which transformed the regional/national standard into a global standard.

An interesting question is whether mandated standards have led to faster adoption of mobile technology. Several recent papers empirically examine whether, other things being equal, early penetration rates for mobile networks were lower (or higher) for countries with multiple incompatible digital standards.[45]

8.2 Instant Messaging[46]

Before the internet there were online computer services. Online computer services like American Online (AOL) and Compuserve were accessed by subscribers through dial-up modems. Once connected, subscribers "surfed" proprietary content provided by their online service and had access to email accounts. AOL introduced instant messaging (IM) for its customers in the late 1980s. Instant messaging allowed its subscribers to engage in nearly real time text-based dialogue. Its popularity soared in 1996 when AOL introduced its "buddy list". The buddy list feature enabled subscribers to determine if other subscribers were online, thereby allowing them to determine who was available to exchange messages. In 1997 AOL introduced AIM which allowed free web based access for non-AOL subscribers to its instant messaging network.

In 1999 a number of firms, including Microsoft and Yahoo! introduced competing IM services, but by this time the installed base of IM subscribers was estimated at 30 million. Without interoperability between the instant messaging networks, the prospects for competing services were not very good. However, there attempts to design their services to interoperate with IM and AIM were blocked by AOL.

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[44] Other developed countries have enabled market competition as well. See Gandal, Salant, and Waverman (2003) for further discussion.

[45] Gruber and Verboven (2001) and Koski and Kretschmer (2002) estimate logistic diffusion models for mobile telecommunications. The papers find that *early* diffusion of second generation mobile telephony was faster in Europe where a single standard (GSM) has been in use, than in other countries (like the U.S.) where multiple standards coexist. According to Cabral and Kretschmer (2004), current diffusion levels are quite similar between the U.S. and Europe. There is clearly a need for additional empirical work on this issue.

[46] This case is based on Faulhaber (2001).

The issue of AOL's refusal to allow competitors access to its installed base raised concerns for the two relevant regulatory agencies, The Federal Trade Commission (FTC) and the Federal Communications Commission (FCC), when America Online (AOL) and Time Warner agreed to merge in January 2000 in a deal that at the time was the largest merger ever.

Although AOL offered basic (text-based) instant messaging service before the proposed merger, emerging instant messaging services such as voice over IP, the exchange of pictures, and streaming video require broadband capabilities. AOL gained significant broadband capabilities with its acquisition of Time-Warner. These advanced messaging services would use the same directory as text-based instant messaging and hence the network effects associated with IM and AIM would also be available to advanced instant messaging offered only by AOL. In essence advanced instant services offered by AOL would start with a significant installed base, providing it perhaps with an insurmountable advantage over rivals. To mitigate this possibility the FCC imposed as a condition for approval of the merger that AOL must offer interoperability with other providers of advanced instant messenger services before it is allowed to offer advanced instant messaging services itself.

While this decision came out of a merger case, the decision to require interoperability has antitrust implications for other settings with network effects. Should Internet backbone providers for example, be required to interconnect with other backbone providers? There clearly are strong network effects in this case as well. Currently there is no such policy and interconnection relies on private agreements.[47]

[47] Cremer, Rey, and Tirole (2000) examine a dominant Internet backbone provider's incentives to 'degrade' the quality of its connection with rival backbone providers. The main concern of the FCC, the Antitrust Division of the Department of Justice in the United States, and Directorate General IV, the antitrust enforcement agency of the European Commission, in the merger between WorldCom and MCI was that it would create just such a dominant Internet backbone provider. The merged firm's market share would be in excess of 50%. By degrading the quality of its interconnection with smaller backbone providers, refusing to interconnect, or charging a price for interconnection it was alleged that MCI/WorldCom could isolate its installed base from smaller rivals, creating differential network effects which would disadvantage them and increase its market power and profits. The merger was allowed to proceed subject to MCI divesting its entire Internet business to Cable & Wireless for $1.75 billion. See Kolasky (1999, pp. 602-604) for details.

8.3 The 56K Modem Standards War[48]

Network effects arise in modem markets because compatible modems are required to transfer data between the sending and receiving parties. Hence, there are direct network effects, similar to those inherent in email or telephone networks.

In September 1996, US Robotics (3COM) submitted a proposed 56K standard to the ITU, the X2.[49] In November 1996, Lucent and Rockwell agreed to make their chipsets interoperable, using the a different standard called K56flex. The K56flex and X2 standards were, however, incompatible. If a consumer used one standard while her Internet Service Provider (ISP) used a different standard, the data transmission speed was not 56K, but rather that of the previous technology 33K.

Both products came to the market in early 1997: demand for higher speed modems was thought to be significant because of the rise of the world wide web and the need to download and display graphic intensive files. The standards war featured extensive efforts by both sides to manipulate the expectations of adopters, with exaggerated claims of dominance made by both sides. However, rather than tip the market, the consensus is that it instead engendered confusion among consumers and ISPs, delaying adoption and retarding sales. Augereau, Greenstein and Rysman (2004, p. 13) estimate that by October just over 50% of ISPs had adopted 56K modems, none of the 7 largest ISPs had upgraded, as did most consumers, waiting for the standards war to work itself out.

Hence, the industry appealed to the ITU to set a standard. In April 1997, the ITU set up a committee to determine a 56K standard. In February 1998 the V.90 standard was approved by the ITU, a standard based on both the X2 and K56flex technologies, but incompatible with both. The V.90 standard was established quite quickly. Mr. P.A. Probst, Chairman of ITU Study Group 16 noted "This is the shortest period of time ever

[48] This section draws heavily from Augereau, Greenstein, and Rysman (2003). See also Shapiro and Varian (1999, pp. 267-270).
[49] 56K means that the maximum speed of the modem was 56,000 bits per second.

taken for an ITU-T modem Recommendation to achieve 'determination' approval status, and demonstrates a commitment by the ITU-T to respond quickly to urgent market needs,"[50] . If a standard had not been agreed upon quickly, it's quite possible that both of the competing 56K standards would have failed.

Interestingly, Augereau, Greenstein and Rysman attribute the failure of the market to tip, despite large network effects, to the strategic behaviour of the ISPs. As suggested by the models of Church and Gandal (1992) and Rysman (2003), small competing ISPs in local markets which upgraded introduced product differentiation and reduced competition by adopting the standard not adopted by their rivals.

8.4 Satellite vs. Cable Television (CATV)

Vertical integration between program producers/packagers (i.e., cable networks), and multiple system cable operators was quite common in the U.S. cable television industry.[51] As a consequence, satellite services and others seeking to offer video-to-the-home services in competition with incumbent CATV operators often experienced difficulty in acquiring programming.

An example is the consent decree entered to in the early 1990s by the United States Department of Justice in the Primestar case. The Department of Justice alleged that the terms establishing Primestar (in 1990) were designed to restrain competition in the market for multichannel subscription television by restricting the access to programming controlled by the cable companies to high-powered direct broadcast satellite (DBS) operators. Primestar was a joint venture among subsidiaries of seven of the major cable television companies and a subsidiary of General Electric. Those seven cable companies had ownership interests or controlling interests in most of the major cable channels. The General Electric subsidiary operated the only available medium-power direct broadcast

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[50] See "Agreement reached on 56K Modem standard," available at http://www.itu.int/newsarchive/press_releases/1998/04.html, accessed May 2, 2004.

[51] For detailed discussion and econometric analysis, see Waterman and Weiss (1996).

satellite. The small dish size and low installation costs of high-powered DBS made it a viable alternative to cable in urban areas.

The consent decree effectively prohibited the seven cable companies from acquiring exclusive distribution rights to the major cable channels or preventing the cable channels from supplying competing distributors.[52] Concerns over the potential for cable system incumbents to deter competition from alternative distributors underlies the 1992 *Cable Act* in the U.S.[53] This *Act* and subsequent Federal Communication Commission rules are intended to prevent programming suppliers from favoring affiliated cable systems over competing distributors in the supply of programming.[54]

Today, direct broadcast satellite (DBS) and cable are the two main platforms in the multi-channel programming. Cable's market share in 2001 was approximately 75%, while satellite services had a 19% market share.[55, 56] Given that cable services held a virtual monopoly before 1992, the 1992 bill seems to have achieved its purpose.

Until recently, satellite provision was perhaps somewhat less desirable because it typically did not offer local channels. However, in 1999, the *Satellite Home Viewer Improvement Act* (SHVIA) was enacted in the United States. Under the relevant FCC rules satellite carriers can carry local TV broadcast channels, though access by a satellite carrier to a local TV channel is subject to consent by the channel. If a satellite carrier has chosen to carry one local TV broadcast channel, it must carry all that ask.[57]

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[52] *United States v. Primestar Partners, L.P. et al.,* Proposed Final Judgement and Consent Decree 58 *Federal Register* 60672 (November 17, 1993).
[53] 47 U.S.C. Section 548.
[54] For a nice summary of the provisions in the *Act* and the FCC's rules, see Federal Communications Commission, *Annual Assessment of the Status of Competition in the Market for the Delivery of Video Programming Tenth Annual Report* 5 January 2004 at pp. 91-92.
[55] This corresponds to17 million households in the United States receiving satellite multi-channel services. Of these, 16 million of these receive DBS, the remaining million using C-band. There are two major satellite companies in the United States, Direct TV and EchoStar, both offering DBS services.
[56] SBCA online http://sbca.com/government/competition.htm "Status of Competition in the Multichannel Video Marketplace."
[57] See FCC NEWS Press Release, September 5, 2001 "FCC AFFIRMS RULES FOR SATELLITE CARRIAGE OF LOCAL TV STATIONS" and Federal Communications Commission, "FACT SHEET

8.5 DVD vs. DIVX Standards War[58]

In April 1997, a consortium of hardware makers and motion picture studios introduced DVD as a replacement for videotapes. The DVD forum wanted to avoid the VHS-Betamax "format war" in the videocassette market. Hence the DVD consortium decided that DVD would be an "open format." Hence, all DVD machines would play all DVD discs.

Circuit City, a major electronics retailer in the United States, introduced a competing format called Digital Video Express, or DIVX in September 1997. In addition to DVD features, it was possible to purchase DIVX discs for a short time period. This is similar to renting movies. In the end DIVX failed. The DVD vs. DIVX standards war highlights an important consideration about the choice between compatibility and incompatibility.

DIVX was "one-way" compatible with DVD in the sense that DIVX players could play DVD discs, but DVD players could not play DIVX discs. The idea was similar to second sourcing and the goal was to convince potential adopters that there would be sufficient software available for the DIVX format. Despite the "one way" compatibility DIVX failed.

Circuit City's choice of one-way compatibility insured potential adopters that purchasers of DIVX machines would not be orphaned. Our earlier discussion suggests that this is a sensible strategy. But there is a difference between one-way compatibility in an "indirect network" and full interoperability in a "direct" network. In the case of one-way compatibility in a "hardware/software" system, software vendors may choose to release their software in the form that is compatible with the incumbent technology since it reaches BOTH audiences. This will mean that very little software will be written specifically for the entrant's technology. In such a case, few consumers will buy the

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Satellite Home Viewer Improvement Act of 1999" December 2000, online at http://www.fcc.gov/mb/shva/shviafac.html.

[58] This discussion draws liberally from Dranove and Gandal (2003) and (2004).

entrant's product, unless the entrant's technology is clearly superior. DIVX failed in part because there was little software written exclusively for its technology.

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Appendix: Modeling Issues[59]

In settings with direct network effects, authors typically employ a utility function of the form:

$$U_{ij} = a_i + N_j^b, \quad 0<b\leq 1. \qquad (1)$$

U_{ij} is the utility to consumer i from network j. This utility depends on a standalone benefit (a_i), which can differ among consumers (and can be equal to zero). The second term represents the network benefit (or network effect), where N_j is the expected size of the network and "b" represents the strength of the network effect. The restriction $0<b\leq 1$ means that the marginal benefit of an additional user on the network is positive, but decreasing or constant in the size of the network. Although the framework is quite simple, N_j (the expected size of the network) is endogenous. This makes it difficult to analytically solve all but the simplest models.

In settings with virtual (or indirect) network effects, the typical utility function is of the form:

$$U_{ij} = c_i + M_j^d, \ 0<d\leq 1. \qquad (2)$$

Here, the utility to consumer i depends on the standalone benefit (c_i) and the number of compatible software varieties available for hardware j (denoted M_j). Again the standalone benefit can be zero. In this case, utility does not depend directly on the number of consumers who join the network. The number of compatible software varieties, however, does depend on and is increasing in the number of consumers who adopt hardware technology j. In other words, $M_j = f(N_j)$, $M_j'(N_j)>0$, so the reduced form (or equilibrium) utility from (2) does increase in the number of consumers that join the network. The modeling complexity is even greater in settings with virtual network

[59] This section draws heavily from Gandal (2002b).

effects because there is an extra set of agents (software firms, in addition to hardware firms and consumers). Additionally, both the number of software varieties and the number of consumers on each network are potentially endogenous.

There are two basic approaches to handling expectations.[60] In the fulfilled expectations approach, consumers' expectations are correct. Although this is probably the most satisfactory approach, it leads to models that are quite difficult to solve analytically.[61] An alternative approach is to assume that consumers have myopic expectations, that is, consumer utility is based only on the network size at the time of purchase. This assumption makes it easier to analytically solve the model and hence allows the models to be more sophisticated. The tradeoff is that myopic expectations are less satisfactory from a modeling standpoint. Since these two assumptions have quite implications, it makes it difficult to compare results across settings, unless the results are robust to both of these "extreme" cases.

Timing issues are important as well. This is especially true in the case in which there are indirect network effects. In such cases, there is interdependence between the hardware adoption decisions of consumers and the supply decision of software manufacturers. Do consumers purchase hardware before software firms choose the hardware technology for which to write software, or do software firms first choose which technology to supply software for? This is the chicken and egg problem. The theoretical literature typically assumes either that consumers first purchase software or that software firms first choose their preferred network.[62]

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[60] This discussion is based on Matutes and Regibeau (1996).
[61] Of course, due to improvements in computing, models can be solved numerically relatively quickly.
[62] In reality, the process probably involves some "give and take," that is, some software firms choose to make their software available for a particular technology, then some consumers make purchases, etc. Gandal, Kende, and Rob (2000) develop a theoretical model and use it to estimate the feedback from hardware to software and vice versa in the CD industry.