OXFORD REVIEW OF ECONOMIC POLICY, VOL. 18, NO. 1

COMPATIBILITY, STANDARDIZATION, AND NETWORK EFFECTS: SOME POLICY IMPLICATIONS

NEIL GANDAL
Tel Aviv University[1]

Given the dramatic growth of the Internet and information-technology industries in general, and the importance of interconnection in these networks, the economics of compatibility and standardization has become mainstream economics. In this paper, I examine several key policy aspects of standard setting in industries with network effects.

I. INTRODUCTION

A network effect exists if consumption benefits depend positively on the total number of consumers who purchase compatible products. If the network effect is direct, as in a physical network, increases in the number of consumers on the same network raise the consumption benefits for everyone on the network. The most common examples are communication networks such as telephone and e-mail networks.

A similar network effect can arise when individuals consume a system that consists of a 'hardware' good and complementary software products. In such a 'hardware/software' system, the consumption benefits of the hardware good are increasing in the variety of compatible software. A virtual (or indirect) network effect arises because increases in the number of users of compatible hardware increase the demand for compatible software and hence the supply of software varieties. The increase in the availability of different software varieties increases the benefit to all consumers who adopt compatible hardware. The consumers who purchase hardware/software systems thus constitute a virtual network.

Classic examples of markets where virtual network effects arise are consumer electronics, such as videocassette recorders and tapes, CD players and compact discs, computer operating systems and

[1] I am grateful to Jeffrey Church, Bronwyn Hall, Pierre Regibeau, and an anonymous referee for helpful comments.

applications programs, and television sets and programming. Virtual network effects also arise in credit-card networks (the credit card is the hardware and the 'software' is the number of merchants that accept the credit card) and bank automatic telling machine (ATM) networks (the bank card is the hardware and the 'software' is the number of ATM terminals from which money can be withdrawn).

In this paper, I examine several key policy aspects of standard setting, both in cases with direct (physical) network effects and in cases with virtual network effects. For the most part, the policy recommendations in settings with direct network effects apply to settings with indirect networks effects. In the case of virtual networks, there may be additional considerations, which are discussed in detail. The goal is not to provide a detailed survey, but rather to focus on key issues that have important policy implications.[2]

The last two decades have witnessed a proliferation of high-tech consumer electronic products that exhibit network effects. In such industries questions of compatibility and standardization are important. (In this context a standard refers to set of technical specifications that enable compatibility among products.) Because of the network effects that are inherent in such industries, successful diffusion of these products is often contingent on a single product winning a battle of market standards or firms achieving compatibility among competing standards.

To summarize, in markets with networks effects, the benefit to consumers from joining a network depends on the number of other consumers who join the network. This has several implications for competition in network markets.

- Expectations of consumers regarding the future size of a network are critical in determining the adoption of network products. Thus consumer expectations that one technology will become a standard may indeed lead to that technology becoming the standard. Expectations depend in part on installed base. Hence history matters.

- Competition in network markets is likely to lead to standardization on a single technology. In other words, the long-term co-existence of competing incompatible standards is unlikely. This is because a small initial advantage will likely influence consumer expectations about the adoption of a particular standard. This in turn will lead to more consumers adopting the standard. Because the value of the product increases in the number of adopters, the value of the network increases to future adopters. Often, consumer expectations are self-fulfilling and an early lead can be transformed into an advantage that is difficult to overcome.

- There is a coordination problem if joining a network involves a sunk investment for consumers.[3] If a network does not grow sufficiently or is abandoned, consumers will be stranded on an 'orphan' technology. In such a case, expected network benefits will not be realized. For this reason, consumers may be unwilling to join a network. This problem is especially severe in the case of virtual networks, since the successful diffusion of such products depends on the availability of complementary products. For example, the success of a computer operating system depends on how many software applications can be run on it. If application software firms do not expect consumers to join the network, they will be reluctant to invest the sunk costs necessary to develop software. This is often referred to as a 'chicken and egg' problem. Similar statements apply to video-game base-units and video games, high-definition television (HDTV) and television programming, CD players and compact discs, and so on.

The paper proceeds as follows. Section II briefly surveys the relevant theoretical framework on network effects and standards. Section III discusses

[2] David and Greenstein (1990) provide a comprehensive survey of earlier work, while Farrell and Klemperer (2002) provide a detailed survey of more recent work. Gilbert (1992), Katz and Shapiro (1994), Gandal (1995), and Matutes and Regibeau (1996) provide selective reviews of the literature.

[3] The discussion here draws from Church and Ware (1998).

key policy issues that have been examined in the literature. I review the relevant literature in the context of examining these policy issues. Section IV briefly concludes.

II. THEORETICAL FRAMEWORK: MODELLING ISSUES

The typical utility function employed in settings with direct network effects is of the form

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

where U_{ij} is the utility to consumer i from network j. This utility depends on the stand-alone benefit (a_i), which can differ among consumers. 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 $0 < b \leq 1$ ensures that the marginal benefit of an additional user on the network is positive, but decreasing or constant in the size of the network. Although this framework seems quite simple, the fact that N_j, the expected size of the network, is endogenous introduces complications that make it difficult to solve analytically all but the simplest models.

The typical utility function in the setting with virtual network effects is

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

where the utility to consumer i depends on the stand-alone benefit (c_i) and the number of compatible software varieties available for hardware j (M_j). In this setting there is not a direct network effect, since 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 increases in the number of consumers who adopt hardware technology j. In other words, $M_j = M_j(N_j)$, $M_j'(N_j) > 0$, so the reduced form (or equilibrium) utility from (2) does increase in the number of consumers that join the network. The modelling complexity is even greater in settings with virtual network effects, because there is an extra level of agents (software firms, as well as hardware firms and consumers) and both the number of software varieties and the number of consumers on each network are potentially endogenous.[4]

There are two basic approaches to handling expectations.[5] In the fulfilled-expectations approach, attention is restricted to equilibria in which consumers' expectations are, indeed, correct. Although it can be argued that this is the most satisfactory approach, it leads to models that are quite difficult to solve analytically; this severely limits the complexity of the model. 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 solve the model analytically and, hence, allows the models to be more sophisticated. The trade-off is that myopic expectations are less satisfactory from a modelling standpoint. Since these two assumptions are polar opposites, it makes it difficult to compare results across settings, unless the results are robust to both of these extreme cases.

Additionally, timing issues may matter. This is especially true in the case in which there are virtual 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 hardware or that software firms first choose their preferred network.[6]

[4] I examine compatibility decisions in the presence of network effects. Some authors have examined compatibility decisions in the absence of direct or indirect network effects—see Matutes and Regibeau (1988) and Economides (1989).

[5] This discussion is based on Matutes and Regibeau (1996).

[6] 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 *et al*. (2000) develop a theoretical model and use it to estimate the feedback from hardware to software and vice versa in the CD industry.

III. KEY POLICY ISSUES: WHAT WE KNOW AND WHAT WE DON'T KNOW

The general modelling framework discussed above has been used to address many issues. In this section I focus on key policy issues and summarize the relevant literature.

(i) Is Compatibility Desirable? The Trade-off Between Standardization and Variety

Arthur (1983) and David (1985) identified the phenomenon of 'locking in' to a standard in settings with direct network effects. They focused on unsponsored technologies, i.e. they did not examine the consequences of oligopolistic competition in industries with network effects. The seminal theoretical contributions on direct network effects in oligopoly markets are series of papers by Farrell and Saloner (1985, 1986*a*,*b*) and Katz and Shapiro (1985, 1986) that examine the social and private incentives to achieve compatibility, that is the trade-off between compatibility and standardization.[7] Chou and Shy (1990) and Church and Gandal (1992) examined similar questions in settings with virtual network effects.[8]

This literature has identified two important welfare results in the static trade-off between 'standardization' (all consumers adopt compatible products) and 'variety' (several incompatible products have positive market shares).

- Market forces often result in suboptimal standardization; that is, left alone the market may fail to achieve standardization when standardization is socially desirable. This result is robust to both physical networks and virtual networks. 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). The last paper shows that suboptimal standardization is most likely to occur when consumers place a relatively high value on software variety.

- Even if the market settles on a standard, the standard may be inferior; that is, social welfare would have been higher had an alternative standard been chosen.[9] This result is also robust to both physical networks and virtual networks.

(ii) How Should Standards be Set?

Assuming that standardization is desirable, how is it best achieved? Some policy-makers have interpreted the results about (i) suboptimal standardization and (ii) the adoption of an inefficient technology to mean that regulators should play an active role in setting standards. Others have urged regulators not to intervene, despite the presence of network effects.[10]

Broadly speaking, there are three ways that standards are set in practice. (i) *De-facto* standards, i.e. standards set primarily by the market—these standards are often proprietary.[11] (ii) Voluntary industry

[7] Some of these papers also examined whether network markets tend to exhibit excess inertia (lock-in to inefficient old technologies) or excess momentum (inefficient adoption of new technologies).

[8] Markovich (2001) examines the trade-off between standardization and variety in a dynamic setting using numerical methods. In her model, both software firms and consumers are strategic. She computes Markov-perfect Nash equilibria using numerical methods to solve a dynamic model that has no analytical solution.

[9] To see this, suppose that all consumers have adopted an 'inferior' standard. No individual consumer has a unilateral incentive to switch because with strong network effects, the value of being part of the network dominates the intrinsic value of the product. Yet all consumers would have been better off if they had jointly chosen the superior standard.

[10] Leibowitz and Margolis (1994) criticize the literature on network effects in part because they believe it does not tell us whether effects identified by the theoretical literature (such as the failure to achieve compatibility) are privately or socially important. They argue that until the literature is able to estimate such effects in a meaningful fashion, the public-policy debates are premature. A small literature has begun to examine empirically technological adoption of products with network effects. The early work has primarily focused on providing empirical evidence of virtual network effects by showing that the value of the hardware depends on the variety of (compatible) complementary software. See Greenstein (1993), Gandal (1994), Saloner and Shepard (1995), Gandal *et al*. (1999).

[11] The PC-operating-system industry provides an example. Owing to a bandwagon effect and the availability of a large amount of Windows-compatible applications software, Microsoft has succeeded in setting standards in the PC-operating-systems industry.

agreements, where standards are often jointly developed—these standards are typically open standards; that is, they are not proprietary.[12] (iii) Standards imposed by national standards bodies (NSBs), or agreed upon by regional or international standards development organizations (SDOs).[13]

Market competition
Advantages to market competition include more technological competition and greater price competition (at least early on) among competing incompatible standards.[14] There are disadvantages to standards competition as well. There is typically a period of uncertainty when standardization is left to market forces; competition among incompatible standards may leave some early adopters stranded with abandoned incompatible equipment. Even if a standard is adopted, it may be inferior.[15] In some cases, uncertainty generated by competition between incompatible standards might lead to the failure of all technologies.[16]

An *ex-post* proprietary standard also has its pros and cons. The static market power conferred upon the winner of a standards competition may lead to a slow rate of adoption owing to high prices as well as a slow-down in the pace of technological change. On the other hand, control of a standard by a single entity reduces coordination problems and uncertainty and may help bandwagon effects get off the ground.

Standard-setting organizations (SSOs)
The small theoretical literature finds that standards committees have desirable properties. Farrell and Saloner (1988) examine the incentives for firms to achieve coordination via standardization committees, and compare committees to (i) a pure market process in which there is no communication among firms and firms can make unilateral standardization choices, and (ii) a hybrid committee/market process in which firms meet in committees and yet can also make unilateral standardization decisions.[17] They find that committees can better set standards in the sense that committees are more likely than market processes to achieve coordination, i.e. standardization. They identify a trade-off here as well: the committee process will typically take longer than if standardization choices were left to the market. Perhaps, not surprisingly, the hybrid process outperforms the other two mechanisms.

Despite the increasing importance of SSOs, there is little systematic research on the topic. The study of the interplay between market competition and SSOs seems to be a very fruitful area for future research.

[12] The DVD (digital video disc) industry provides an example of a jointly developed standard. Throughout the 1990s, video hardware and software manufacturers sought a digital format to replace videocassettes. In order to avoid another Beta/VHS format war, hardware manufacturers, led by Sony, Toshiba, and Panasonic, and movie studios, led by Warner and Columbia (a division of Sony), worked together to establish a single standard. The result was the non-proprietary or 'open' DVD standard.

[13] Examples of SDOs include the International Telecommunications Union (ITU), the oldest international standards body in the world, and the International Electrotechnical Commission (IEC). Given the importance of compatibility among international phone networks, the standards set by the ITU are done so by international consensus.

[14] Katz and Shapiro (1986) analyse a setting with two incompatible technologies and they investigate whether the market, by adopting only one of the competing technologies, establishes a *de-facto* standard. One technology has a cost advantage in the first period and the other technology has a cost advantage in the second. Their model illustrates that the combination of network effects and incompatible products leads to intense price competition in early periods. Firms are willing to discount their prices heavily in early periods in order to build up an installed base advantage since this is attractive to later consumers.

[15] Katz and Shapiro (1986) show that the 'second' technology is adopted for many parameter values for which it is socially optimal to adopt the first technology. This result is known as excess momentum. The market 'bias' against the first technology is essentially a commitment issue. This is because the firm with the second technology (the lower marginal cost in the second period) can price below marginal cost in the first period, while the firm with the first technology cannot commit to price below marginal cost in the second period.

[16] Audio quadraphonic sound provides an example. In the early 1970s, this technology promised concert-like music at home. Two competing incompatible technologies were introduced by Columbia and JVC/RCA. Despite the fact that RCA and Columbia were the dominant firms in record production and both held rights to lots of key titles, consumer concerns about being orphaned led to slow sales growth for both systems. By the mid-1970s, both technologies had failed. See Postrel (1990) for more details. This idea has been modelled by Kretschmer (2001).

[17] 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.

Mandated standards
Another alternative to market-mediated standards is the setting of standards by regulators. A benefit from mandated standards is that *in theory* they can be set quickly.[18] Also, mandated standards ensure coordination on a single technology.

A disadvantage of mandated standards is that there is less price and technological competition. Additionally, owing to asymmetric information, firms typically know more about both costs and potential technological progress than regulators. This makes it difficult for regulators to set standards. Another problem is rent-seeking behaviour induced by the prospect of mandated standards. Finally, setting a standard too early often implies deciding without relevant information that would be gained by waiting. In the case of HDTV in Japan, the government mandated a standard at an early stage. Most industry experts believe that the delay in adopting a standard and the competition among competing standards led to the USA receiving a higher quality HDTV system.[19]

(iii) Competition/Antitrust Policy in Settings with Network Effects

Network considerations affect all aspects of antitrust/competition policy. Here I examine a few key areas.

Innovation and network effects
Many high-tech consumer electronic products exhibit strong network effects. These industries also exhibit tremendous rates of innovation. Hence antitrust policies in network industries must take account of the strength of network efforts as well as the importance (and pace) of innovation.[20]

There is a small literature on the interaction between compatibility choices and technological progress/ product introduction. The key question examined by the literature is how compatibility, or its absence, affects the rate of technological progress or the time when products are introduced. Although little in general can be said about the relationship between compatibility and product introduction/R&D, some progress has been made as the work surveyed below shows.[21] In particular, two general results that seem quite robust are (i) compatibility results in the optimal timing of product introduction and (ii) incompatibility speeds up product introduction.

Katz and Shapiro (1992) produce a dynamic model with fulfilled expectations. In order to make it tractable, they consider a setting in which one of two competing products has been introduced and the second firm must decide (i) when to introduce its product, and (ii) whether to make its product compatible with the initial product. They show that the firm introducing the new technology is biased against compatibility.

Regibeau and Rockett (1996) similarly assume that the rate of technological progress is exogenous. Like Katz and Shapiro (1992), they endogenize both the compatibility decision and the product introduction date. Unlike Katz and Shapiro (1992), neither of the two competitors has introduced a product. In order to make the model tractable, they assume that consumers have myopic expectations about the firms' installed bases. This allows them to analyse a more complex introduction game. They find that compatibility speeds up the introduction of the first product, but increases the delay before the second product is introduced. They also find that when firms can credibly commit themselves to a standard in the early development stage, they agree to produce compatible products.

Kristiansen (1998) allows for endogenous product introduction rates and endogenous technical progress, but in a restrictive model in which firms can choose to introduce their technology in either period 2 or period 3. In period 1, the firms develop their technology. It is assumed that the R&D cost of introducing the technology in period 2 is higher than the R&D cost of introducing the technology in

[18] See Cabral (2000) for further discussion. In practice, mandated standards are not necessarily set quickly because it may not be in the interests of the relevant firms to set a standard quickly.
[19] See Farrell and Shapiro (1992).
[20] See Church and Ware (2001) for more discussion.
[21] This is, in part, because settings with endogenous compatibility choices and endogenous product introduction dates are difficult to solve analytically, even if technological change is exogenous.

period 3.[22] The model assumes that the technologies are incompatible. He finds that network effects lead to the technologies being introduced too early.

An interesting point in Kristiansen (1998) is that government intervention to set a standard at the beginning of the third stage can actually exacerbate the inefficient early introduction of products.[23] Hence, if a regulator cannot impose a standard *ex ante* (due to lack of information, etc.), government intervention *ex post* will not lead to an improvement relative to the market.[24]

Integration and foreclosure in markets with virtual network effects

One classic anecdote illustrating the critical role that complementary products play in the adoption of systems is the failure of the Betamax videocassette recorder (VCR) technology. The Betamax technology was apparently—'on its own'— as good as the competing incompatible VHS technology.[25] None the less, by 1981, VHS held a 66-per-cent share of the VCR installed base. When pre-recorded videocassettes became important in the early 1980s, rental stores preferred to carry VHS tapes because of their installed-base advantage. The dearth of Betamax tapes 'tipped' the market to VHS, which became the *de-facto* standard in 1988.

In the case of Betamax versus VHS, neither of the two 'hardware' technologies controlled the market for software (the movies). Such control has raised antitrust issues. The concern is that hardware control of software will foreclose other hardware providers.

Church and Gandal (1996) assess the effect of hardware control of software provision in system markets. They show that when an incumbent can commit itself to an installed base of software, it can create strategic entry barriers that prevent an efficient entrant from entering the market. Bresnahan (1999) arrives at a similar conclusion. These papers suggest that network effects can enable a monopolist to create strategic entry barriers.

Church and Gandal (2000) examine theoretically the possibility of such foreclosure in system markets where a system is composed of a hardware good and complementary software and the value of the system depends on the availability of software. Foreclosure occurs when a hardware firm merges with a software firm and the integrated firm makes its software incompatible with a rival technology or system. They find that foreclosure can be an equilibrium outcome where both the merger and compatibility decisions are part of a multistage game that permits the foreclosed hardware firm to play a number of counter-strategies. Further, they find that foreclosure can be an effective strategy to monopolize the hardware market.

Hence, the antitrust concern about such foreclosure seems well founded. In practice, antitrust authorities often require arrangements to ensure access to the software of a merged (hardware/software) entity. An example is the US Federal Trade Commission's (FTC) 1995 consent decree with Silicon Graphics, Inc. (SGI), which allowed SGI to acquire two of the three leading graphic entertainment software companies.[26] One of the reasons behind the FTC's challenge was that competing manufacturers of work stations would be foreclosed from two important independent providers of graphic software. One of the provisions of the consent agreement is that SGI make the two major entertainment graphics software programs it acquired from Alias Research compatible with the hardware work stations of a competitor.

Antitrust policy towards SSOs

Industry cooperation typically takes the form of a private consortium where the firms come together and reach an agreement on a standard. The theo-

[22] Kristiansen (1998) assumes rational expectations; despite this assumption he is able to solve the model because of the limit on the number of periods of R&D competition.

[23] This assumes that the policy is known in advance.

[24] This is reminiscent of Farrell and Saloner (1992). They examine the incentives for *ex-post* standardization in the context of converters and show that converters can give rise to suboptimal incentives to produce *ex-ante* compatible products.

[25] Park (1997) cites a *1982 Consumer Reports* publication that tested various VCR models. The report concluded that there was no significant difference in the characteristics or qualities of the two platforms.

[26] The final consent decree is summarized at http://www.ftc.gov/opa/1995/9511/sil2g.htm

retical literature suggests that SSOs are more likely to lead to standardization than a market-mediated process. This suggests that SSOs can play a useful role in achieving compatibility.

But such horizontal agreements among competitors raise antitrust issues. Legal scholars are concerned that SSOs have the potential to manipulate standards committees. These consortia will likely have to obtain exemptions from antitrust authorities as they did in the case of DVD.[27]

Other 'antitrust issues' raised by private consortia are the exchange of information on costs, bias in the choice of the standard, and refusal to license the necessary technology to non-members. What should be the antitrust policy towards standard setting via committee? Lemley and McGowan (1998) suggest that an appropriate antitrust policy might be to allow standard-setting consortia, but guarantee that all firms have access to the standard-setting process.[28]

Merger policy
Network effects affect merger policy because of issues related to compatibility and interoperability. The merger between America Online (AOL) and Time Warner provides a good overview of the issues.[29] Announced in January 2000, it represented the largest proposed merger of all time.

One of the main concerns of the two relevant regulatory agencies, the FTC and the Federal Communications Commission (FCC), was interoperability or compatibility between AOL's instant-messaging service and those of competitors.[30] This concern arose from the presence of network effects. Although AOL offered a basic (text-based) instant-messaging service before the proposed merger, emerging instant-messaging services, such as voice-over Internet protocol, the exchange of pictures, and streaming video, require broadband capabilities. AOL gained significant broadband capabilities with its acquisition of Time Warner. Hence, the FCC imposed the condition that AOL must offer interoperability with other providers of advanced instant-messaging services before it is allowed to offer such 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.[31]

Requiring backward compatibility
Regulators occasionally require that a new technology be backward compatible. In 1997, for example, the FCC set down the guidelines for the new digital HDTV standard. Viewers with regular National Television System Committee (NTSC) televisions will be able to watch new broadcasts with a 'down-converter' box, which will provide a somewhat improved image. Viewers with new HDTVs will be able to watch old NTSC programmes if they have a second (analog) tuner built in.[32] This is similar to the strategy employed by the FCC in the early 1950s when a backward-compatible prototype was chosen.[33]

Backward compatibility has benefits as well as costs. Benefits associated with backward compatibility are that old consumers are not stranded and that providing backward compatibility (and the associated software variety) will hasten adoption of the new technology. An additional benefit is that

[27] See Merges (1998).
[28] Even if everyone is welcome around the table, effective 'participation' depends on the decision rules of the SSO. If the decision rule requires unanimity, then expanding participation might have a cost in terms of the speed of decision-making. See Lemley (2001) for a first look at these issues.
[29] The discussion in this section draws liberally on Faulhaber (2001).
[30] AOL had a very large installed base of subscribers when other firms (including Yahoo and Microsoft) began offering competing instant-messaging services. In order to benefit from network effects, AOL's rivals designed their systems to be compatible with AOL's service. AOL blocked the interconnection, citing safety, privacy, and security concerns—see Faulhaber (2001).
[31] Cremer *et al*. (2000) examine a dominant Internet backbone provider's incentives to 'degrade' the quality of its connection with rival backbone providers.
[32] See 'HDTV: How the Picture Looks Now', *Business Week*, 26 May 1997, and 'Should you Roll Out the Welcome Mat for HDTV?', *The New York Times*, 27 April 1997.
[33] See Farrell and Shapiro (1992) for more on the role of standard setting in HDTV.

compatibility leads to the optimal rate of technological progress in many settings.[34] In terms of costs, it is claimed that backward compatibility requires additional development costs and hence slows down innovation. To the best of my knowledge, there is no thorough theoretical analysis of these issues.[35]

Gandal *et al*. (2000) develop a structural model and use it to estimate the feedback from hardware to software and vice versa in the CD industry. The advantage of the structural methodology is that it enables researchers to conduct counterfactuals. Gandal *et al*. (2000) show that if it had been possible to make CD players compatible with LPs, compatibility could have accelerated the adoption process by more than a year. While such a counterfactual is purely a 'thought experiment' for CD players, it has public-policy relevance for other systems regarding the benefits of backward compatibility.[36]

(iv) Intellectual Property Rights in the Presence of Network Effects

Many economists and legal scholars have argued that intellectual property rights should be interpreted narrowly in settings with network effects.[37] This is because, in the presence of network effects, copyright and other forms of intellectual property protection may confer monopoly power without any significant innovation. In many cases, consumers highly value the benefits from compatibility, rather than the differences in the other characteristics of the products. Thus the presence of network effects may turn the initial choices of small groups of users into *de-facto* standards.

Copyright (and other forms of intellectual property protection) may also create entry barriers if intellectual property protection also extends to the interface aspects of network products. Many economists and legal scholars have argued that intellectual property rights should be limited in a way that facilitates compatibility or interoperability between competing products in markets with network effects. This might mean limited intellectual protection for the interface aspects of network products.[38] Lemley and McGowan (1998) suggest that limited copyright protection for interfaces would apply in cases when a firm improves an interface.[39]

The Council of European Communities Directive No. 91/250 (May 1991) on the legal protection of computer programs is in the same spirit. It authorizes the reproduction of copyrighted code under circumstances when

> reproduction of the code and translation of its form . . . are indispensable to obtain the necessary information to achieve the interoperability of an independently created program with other programs. . . . [The objective] is to make it possible to connect all components of a computer system, including those of different manufacturers, so that they can work together.[40]

(v) International Policy Issues in Settings with Network Effects

Despite the fact that many industries characterized by 'network effects' (personal computers, telecommunications, consumer electronics products) are global, the literature on network effects has almost exclusively focused on closed economies.[41] The analysis of compatibility standards differs between closed-economy and open-economy contexts for several reasons. The most important difference from a policy standpoint is that the analysis of closed economies ignores any gains that might come from international coordination of standards. When there are network effects, the benefits from standardiza-

[34] See Matutes and Regibeau (1996).

[35] See Choi (1994) for monopoly incentives to makes successive versions of products incompatible. See also Fudenberg and Tirole (1998) for monopoly pricing of upgrades.

[36] Rysman (2001) also uses a structural model to perform counterfactuals in the market for 'Yellow Pages'.

[37] Indeed, several economists authored an amicus brief on the issue that was submitted to the US Supreme Court. The brief can be found online at http://elsa.berkeley.edu/~woroch/amicus.pdf.

[38] See Menell (1998) and Lemley and McGowan (1998).

[39] Hence, in the case of the Borland spreadsheet and the Lotus interface, Borland would have been allowed to employ the Lotus interface since Borland's innovation improved the operation of the interface. On the other hand, in the case in which a firm simply imitates an interface, there would be full copyright protection for the original interface.

[40] See http://europa.eu.int/eur-lex/en/lif/dat/1991/en_391L0250.html

[41] Exceptions include Gandal and Shy (2001) and Barrett and Yang (2001).

tion increase in the size of the network, regardless of whether the consumers are foreign or domestic.

Individual governments do not typically take into account the gains from the international coordination of standards policies. Broadcast television is an example. The NTSC system was developed in the USA in 1954. The Sequential Couleur Avec Memoire (SECAM) system and the Phase Alternate Lines (PAL) system were developed in the early 1960s, SECAM in France and PAL in West Germany. All three standards are incompatible. The USA and Japan adopted NTSC, while the PAL system was adopted by most countries in western Europe (except France). France and eastern European countries adopted SECAM. This fragmentation likely slowed the development of a global market for television receivers. In order to sell television sets in France, foreign manufacturers had to adapt (convert) the receivers to the SECAM standard. Because television broadcasting systems are incompatible, videocassettes produced for PAL cannot be played on NTSC television receivers (and vice versa).

One solution that might internalize network effects across borders is a shift from national to regional or international standards committees. David and Shurmer (1996) provide qualitative evidence that such a shift has been taking place, especially in the case of information and communications technologies. They attribute this shift to advances in information and communications technologies and the importance of technical compatibility within products (such as computer operating systems and applications software and consumer electronics products) that employ these new technologies. According to the authors, 'the information and communications technologies' impact upon the standardization regime has been profound' (David and Shurmer, 1996, p. 797).

IV. CONCLUSION

Network effects are prevalent in many markets, especially high-tech and information-technology markets. This paper has provided a brief overview of some key policy issues. 'Network economics' was at one time considered a rather esoteric field of research and examining the 'tradeoff between the private and social incentives to achieve compatibility' seemed like a fairly abstract research topic. Given the dramatic growth of the Internet and information-technology industries in general, and the importance of interconnection in these networks, the economics of compatibility and standardization has become mainstream economics. It is to be hoped that the broader interest in the topic will help shed light on the many unanswered policy issues in this field.

REFERENCES

Arthur, B. (1983), 'On Competing Technologies and Historically Small Events: The Dynamics of Choice Under Increasing Returns', Stanford University, mimeo.

Barrett, C., and Yang, Y. (2001), 'Rational Incompatibility with International Product Standards', *Journal of International Economics*, **54**, 171–91.

Bresnahan, T. (1999), 'New Modes of Competition: Implications for the Future Structure of the Computer Industry', in J. A. Eisenach and T. M. Lenard (eds), *Competition, Innovation and the Microsoft Monopoly: Antitrust in the Digital Marketplace*, Boston, MA, Dordrecht, and London, Kluwer.

Cabral, L. (2000), *Introduction to Industrial Organization*, Cambridge, MA, MIT Press.

Choi, J. (1994), 'Network Externality, Compatibility Choice, and Planned Obsolescence', *Journal of Industrial Economics*, **42**, 167–82.

Chou, C., and Shy, O. (1990), 'Network Effects without Network Externalities', *International Journal of Industrial Organization*, **8**, 259–70.

Church, J., and Gandal, N. (1992), 'Network Effects, Software Provision and Standardization', *Journal of Industrial Economics*, **40**, 85–104.

— — (1996), 'Strategic Entry Deterrence: Complementary Products as Installed Base', *European Journal of Political Economy*, **12**, 331–54.

— — (2000), 'Systems Competition, Vertical Merger, and Foreclosure', *Journal of Economics and Management Strategy*, **9**, 25–51.

Church, J., and Ware, R. (1998), 'Network Industries, Intellectual Property Rights, and Competition Policy', in N. Gallini and R. Anderson (eds), *Competition Policy, Intellectual Property Rights and International Economic Integration*, Calgary, University of Calgary Press, 227–85.
— — (2001), 'Antitrust in High Tech Industries', University of Calgary, mimeo.
Cremer, J., Rey, P., and Tirole, J. (2000), 'Connectivity on the Commercial Internet', *Journal of Industrial Economics*, **48**, 433–72.
David, P. (1985), 'Clio and the Economics of QWERTY', *American Economic Review*, **75**, 332–6.
— Greenstein, S. (1990), 'The Economics of Compatibility Standards: An Introduction to Recent Research', *Economics of Innovation and New Technology*, **1**, 3–41.
— Shurmer, M. (1996), 'Formal Standards-setting for Global Telecommunications and Information Services', *Telecommunications Policy*, **20**, 789–815.
Economides, N. (1989), 'Desirability of Compatibility in the Absence of Network Externalities', *American Economic Review*, **79**, 1165–81.
Farrell, J., and Klemperer, P. (2002), 'Coordination and Lock-in: Competition with Switching Costs and Network Effects', forthcoming in *Handbook of Industrial Organization, Vol. 3*, available at www.paulklemperer.org
— Saloner, G. (1985), 'Standardization, Compatibility and Innovation', *RAND Journal of Economics*, **16**, 70–83.
— — (1986*a*), 'Standardization and Variety', *Economics Letters*, **20**, 71–4.
— — (1986*b*), 'Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation', *American Economic Review*, **76**(5), 940–55
— — (1988), 'Coordination through Committees and Markets', *RAND Journal of Economics*, **19**(2), 235–52.
— — (1992), 'Converters, Compatibility and the Control of Interfaces', *Journal of Industrial Economics*, **40**, 9–35.
— Shapiro, C. (1992), 'Standard Setting in High-definition Television', *Brookings Papers: Microeconomics*, 1–93.
Faulhaber, G. (2001), 'Network Effects and Merger Analysis: Instant Messaging and the AOL/Time Warner Case', mimeo, available at http://rider.wharton.upenn.edu/~faulhabe/NETWORK%20EFFECTS%20AND%20MERGER%20ANALYSIS.pdf
Fudenberg, D., and Tirole, J. (1998), 'Upgrades, Tradeins, and Buybacks', *RAND Journal of Economics*, **29**, 235–58.
Gandal, N. (1994), 'Hedonic Price Indexes for Spreadsheets and an Empirical Test for Network Externalities', *RAND Journal of Economics*, **25**, 160–70.
— (1995), 'A Selective Survey of the Literature on Indirect Network Externalities', *Research in Law and Economics*, **17**, 23–31.
— Shy, O. (2001), 'Standardization Policy and International Trade', *Journal of International Economics*, **53**, 363–83.
— Greenstein, S., and Salant, D. (1999), 'Adoptions and Orphans in the Early Microcomputer Market', *Journal of Industrial Economics*, **47**, 87–105.
— Kende, M., and Rob, R. (2000), 'The Dynamics of Technological Adoption in Hardware/Software Systems: The Case of Compact Disc Players', *RAND Journal of Economics*, **31**, 43–61.
Gilbert, R. (1992), 'Symposium on Compatibility: Incentives and Market Structure', *Journal of Industrial Economics*, **40**, 1–8.
Greenstein, S. (1993), 'Did Installed Base give an Incumbent any (Measurable) Advantages in Federal Computer Procurement', *RAND Journal of Economics*, **24**, 19–39.
Katz, M., and Shapiro, C. (1985), 'Network Externalities, Competition, and Compatibility', *American Economic Review*, **75**, 424–440.
— — (1986), 'Technology Adoption in the Presence of Network Externalities', *Journal of Political Economy*, **94**, 822–41.
— — (1992), 'Product Introduction with Network Externalities', *Journal of Industrial Economics*, **40**, 55–83.
— — (1994), 'Systems Competition and Network Effects', *Journal of Economic Perspectives*, **8**, 93–115.
Kretschmer, T. (2001), 'Competition, Inertia, and Network Effects', London School of Economics, mimeo.
Kristiansen, E. (1998), 'R&D in the Presence of Network Externalities: Timing and Compatibility', *RAND Journal of Economics*, **29**, 531–47.
Lemley, M. (2001), 'Antitrust, Intellectual Property and Standard-setting Organizations', mimeo (http://www.arxiv.org/ftp/cs/papers/0109/0109037.pdf).
— McGowan, D. (1998), 'Legal Implications of Network Economic Effects', *California Law Review*.
Liebowitz, S., and Margolis, S. (1994), 'Network Externality: An Uncommon Tragedy', *Journal of Economic Perspectives*, **8**(2), 133–50.
Markovich, S. (2001), 'Snowball: The Evolution of Dynamic Markets with Network Externalities', Tel Aviv University, mimeo.

Matutes, C., and Regibeau, P. (1988), 'Mix and Match: Product Compatibility without Network Externalities', *RAND Journal of Economics*, **19**, 221–34.

— — (1996), 'A Selective Review of the Economics of Standardization: Entry Deterrence, Technological Progress, and International Competition', *European Journal of Political Economy*, **12**, 183–206.

Menell, P. (1998), 'An Epitaph for Traditional Copyright Protection of Network Features of Computer Software', *Antitrust Bulletin*, **43**(3–4), 651–713.

Merges, R. (1998), 'Institutions for Intellectual Property Transactions: The Case of Patent Pools', UC Berkeley, mimeo.

Park, S. (1997), 'VHS/Beta and Network Externalities', Department of Economics, State University of New York, Stonybrook, mimeo.

Postrel, S. (1990), 'Competing Networks and Proprietary Standards: The Case of Quadraphonic Sounds', *Journal of Industrial Economics*, **39**, 169–85.

Regibeau, P., and Rockett, K. (1996), 'The Timing of Product Introduction and the Credibility of Compatibility Decisions', *International Journal of Industrial Organization*, **14**, 801–23.

Rysman, M. (2001), 'Competition between Networks: A Study of the Market for Yellow Pages', Boston University, mimeo.

Saloner, G., and Shepard, A. (1995), 'Adoption of Technologies with Network Externalities: An Empirical Examination of the Adoption of Automated Teller Machines', *RAND Journal of Economics*, **26**, 479–501.