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UNLOCKING TECHNOLOGY: ANTITRUST AND INNOVATION

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ABSTRACT

Technology lock-in advocates argue that governments should step in to coordinate technology adoption decisions. Due to the presence of network effects, advocates warn that consumers may fail to adopt the best technology, thus missing out on potential benefits. Even worse, consumers may split, adopting multiple technologies and thus missing out on the benefits of network effects. Due to coordination problems, consumers cannot mitigate the effects of bad technology choices and the economy becomes stuck with inferior innovations. This article demonstrates that consumer coordination solves the underlying network effects problem, thus eliminating technology lock-in. Network effects are confined at most to the information and communications technology and selected electronics industries, which have developed mechanisms for interconnection and interoperability. Firms have incentives to provide interconnection and interoperability when it is efficient to do so. Rapid technological innovation is apparent whereas technology lock-in is a rare phenomenon. Antitrust policy founded on technology lock-in arguments is misguided and is likely to damage incentives for innovation.

I. INTRODUCTION

"Technology lock-in" has joined the pantheon of highly honored justifications for government intervention in innovation that should be laid to rest. The concept of technology lock-in has begun to exert influence in antitrust policy, appearing in *Microsoft v. Commission.*[1] Advocates argue that technology

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[1] The Commission of the European Communities (Commission) predicted that Microsoft's Media Player would dominate other forms of players. The arguments supporting the prediction were fundamentally flawed and not surprisingly the prediction proved to be wildly

lock-in occurs when markets adopt an inferior technology and that government action is required to remedy the situation. Yet, the notion that governments can make the best choice among innovations, but markets cannot, is the "fatal conceit" of technology lock-in.

In this article, I demonstrate that the arguments supporting the idea of technology lock-in are fundamentally flawed as is much of the evidence for the phenomenon. The desirability of government intervention is suspect as well, particularly as government remediation is built into the definition of the problem. I show how markets effectively coordinate decisions to adopt innovations. Market participants have economic incentives to make efficient choices among innovations. The concept of technology lock-in thus is likely to misguide public policy. To avoid disrupting incentives for innovation, public policy makers should exercise more forbearance than is usual in markets for technology.

The concept of technology lock-in predicts market failure on a colossal scale. For Brian Arthur, the economy experiences "lock-in by history."[2] Because technological advances are ubiquitous in the modern economy, such a systematic market failure potentially would entail losses equal to a substantial share of Gross Domestic Product. In addition, because technological progress is an important contributor to increases in productivity, a systematic failure of technology markets would affect the rate of economic growth significantly. So large a danger to the economy begs the question, how likely is technology lock-in?

Technology lock-in is almost entirely based on one concept – "network externalities."[3] Network effects refer to mutual benefits that consumers receive from consuming the same good, such as telecommunications.[4] If consumers cannot coordinate their purchases, they may miss out on some of

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inaccurate, with the rise of Adobe Flash Player, Apple iTunes, and other market alternatives. The Commission further maintained that Microsoft's server operating system would have an unfair advantage over other server operating systems. *See Microsoft Corporation against Commission of the European Communities*, Case T-201/04, Ruling on September 17, 2007 by the European Court of First Instance; *see also* Commission of the European Communities, Commission decision of March 24, 2004, relating to a proceeding under Article 82 of the EC Treaty (Case COMP/C-3/37.792 Microsoft), Brussels, April 21, 2004, C(2004)900 final.

[2] W.B. Arthur, *Competing Technologies, Increasing Returns, and Lock-in by Historical Events*, 97 ECON. J. 116 (March 1989). Arthur claims that recognizing positive feedbacks creates an entirely new economics. *See also* W.B. Arthur, INCREASING RETURNS AND PATH DEPENDENCE IN THE ECONOMY (Ann Arbor, MI: University of Michigan Press 1994); P. David, *Clio and the Economics of QWERTY*, 75 AMERICAN ECON. REV. 332 (1985); P. David, *Heroes, Herds and Hysteresis in Technological History: Thomas Edison and "The Battle of the Systems" Reconsidered*, 1 INDUS. & CORP. CHANGE 129 (1992).

[3] There is some mention of switching costs but the network externalities explanation is predominant in the literature. I address switching costs later in the discussion.

[4] For a critical discussion of the concept of network effects that is closely related to the arguments in the present article, see D.F. Spulber, *Consumer Coordination in the Small and in*

these "social benefits," leading to a market failure from "positive externalities." The concept of "externalities" refers to those economic interactions that are inefficient because they take place outside of market transactions.

The technology lock-in assertion transfers the "network externalities" story from the decision to purchase a product to the decision to adopt an innovation. These decisions are one and the same when the innovation takes the form of a new product. Technology lock-in is said to occur when consumers choose between products each of which has network effects. Technology lock-in thus recycles the idea of network effects.

Technology lock-in is an inevitable consequence of network externalities because of the presumption that the market has already failed. Yet, there should not be two social costs from one market failure. If the market failure were corrected, or indeed if the market failure did not happen, further inefficiencies in technology adoption would not occur either. Network effects are the underlying problem, not technology lock-in. Technology lock-in thus rises or falls depending on whether or not network externalities exist.

Network externalities lead to inefficient technology adoption decisions because of the assumed presence of network effects, and the assumed lack of consumer coordination. Consumers get stuck with an inferior technology because they are inefficiently chasing expectations about which technology will be popular and yield the desired benefits of network effects. Alternatively, consumers form incorrect expectations and they split their technology choices among multiple technologies, thus missing out on the mutual benefits of network effects. Still further, consumers are reluctant to switch to a better technology because they enjoy the benefits of network effects, or they are too eager to adopt a new technology, ignoring the network benefits that their adoption would confer on the existing base of users.

Although technology lock-in has captured the imagination of some public policy makers and academics, the phenomenon appears rare. There is some anecdotal evidence for lock-in but some of these studies have been challenged and shown to be flawed.[5] There is no support for a prediction of widespread inertia in technology adoption. Basic research advances are widespread in practically every field of science and mathematics. Technological change exists throughout the economy. Firms continue to make significant investments in research and development (R&D), indicating that they anticipate returns to innovation. New products, industrial

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the Large; Implications for Antitrust in Markets with Network Effects, 4 J. COMPETITION L. & ECON. 1 (June 2008).

[5] *See* S.J. Liebowitz & S.E. Margolis, *The Fable of the Keys*, 33 J.L. & ECON. 1 (1990); S.J. Liebowitz & S.E. Margolis, WINNERS, LOSERS, AND MICROSOFT: COMPETITION AND ANTITRUST IN HIGH TECHNOLOGY (Oakland, CA: Independent Institute 1999).

processes, and transaction methods continue to be adopted in practically every industry.

Despite being rarely observed, technology lock-in remains influential in competition policy. This makes it necessary to understand whether technology lock-in has any economic consequences. I show in the present discussion that three crucial factors explain why technology lock-in is unlikely to occur. These factors limit any potential economic damage from technology lock-in.

First, consumer coordination mitigates or eliminates technology lock-in. Because network effects are the main driver of lock-in in theoretical arguments, it is necessary to determine whether network effects lead to technology lock-in in practice. Even if network effects do exist, consumer coordination is likely to take advantage of any potential benefits. When there are small numbers of consumers, they can engage in Coasian bargaining, what I call "coordination in the small." Consumers can coordinate their innovation adoption decisions in light of any mutual benefits from consumption. When there are large numbers of consumers, firms can apply various instruments to coordinate the choices of large numbers of consumers corresponding to Hayek's "spontaneous order," what I call "coordination in the large."[6] Coordination by consumers and firms internalizes the benefits of network effects, eliminating network externalities and avoiding technology lock-in.

Second, even if the phenomenon of technology lock-in exists, it is necessarily confined to particular network industries. Moreover, the impact of lock-in is limited in those industries that have institutions designed to cope with technological change. Consumer interactions through networks are ubiquitous in the economy, encompassing social networks, transaction networks, and transport networks. However, network effects depend on the particular features of goods and services. These product features require the use of physical and virtual networks in the transmission of information. The relevant network industries are the information and communications technology and selected electronics (ICTE) industries.[7] This helps to explain why examples and applications of the concept of technology lock-in are almost invariably being drawn from the ICTE industries. Technological change occurs in every part of the economy, but technology lock-in necessarily is limited to the ICTE industries, which have institutional mechanisms for addressing technological change.

Third, firms in network industries have strong incentives to provide interoperability when necessary. This guarantees that the potential benefits from

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[6] *See* Spulber (2007), *supra* note 4.

[7] For a comprehensive overview, see particularly C. Forman & A. Goldfarb, *Diffusion of Information and Communication Technologies to Business*, *in* HANDBOOK IN INFORMATION SYSTEMS 1–52 (T. Hendershott, ed., Amsterdam: Elsevier, vol. 1 2006).

network effects are realized without the need to choose a single technology. Thus, the potential economic effects of lock-in are negligible in the ICTE industries. Interoperability is common in the network industries. In communications, almost all communications networks interoperate. Access to telecommunications is nearly universal and almost all networks are interconnected. An individual user that connects to any network can communicate with almost any user on any other network. In information systems, interoperability is the norm with significant exchange of information across computers, operating systems, and software applications. Interoperability is built into products in the ICTE industries. In addition, ICTE industry associations promote technology standards that bring benefits from technology adoption due to network effects. Also, firms have incentives to supply conversion technologies bridging diverse product standards in the ICTE industries. Of course, not all products need to interoperate. The sheer diversity of products, even some that do not interoperate, indicates areas where the benefits of product diversity outweigh the benefits of standardization.

The concept of network effects has made its influence felt in antitrust. The combination of network effects and technology lock-in plays a prominent role in *Microsoft v. Commission*.[8] Network effects were said to lead to market dominance in *United States v. Microsoft*.[9] The concept of network effects plays a role in various other cases.[10] The DOJ's complaints against Visa and MasterCard emphasize the card issuers' networks of banks, and the District Court found that "network services output is necessarily decreased and network price competition restrained by the exclusionary rules."[11] Technology lock-in and network effects are critical aspects over the policy debate of network neutrality.[12] In *Kodak*, the Court applied lock-in arguments based on switching costs. The Court in *Kodak* found tying to be a problem because the high cost of purchasing copiers resulted in switching

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[8] *Microsoft Corporation against Commission of the European Communities*, Case T-201/04, Ruling on September 17, 2007 by the European Court of First Instance.

[9] The appellate court in *Microsoft* stated that "[i]n markets characterized by network effects, one product or standard tends towards dominance, because the utility that a user derives from consumption of the good increases with the number of other agents consuming the good." *United States v. Microsoft Corp.*, 253 F.3d 34, 49 (D.C. Cir.), cert. denied, 534 U.S. 952 (2001). *See also* Novell, Inc. v. Microsoft Corp., 505 F.3d 302 (4th Cir. 2007).

[10] Alabama Power Co. v. FCC, 311 F.3d 1357 (11th Cir. 2002); Flying J, Inc. v. Comdata Network, Inc., 405 F.3d 821 (10th Cir. 2005); Covad Communs. Co. v. Bellsouth Corp., 314 F.3d 1282 (11th Cir. 2002); Poller v. Columbia Broadcasting System, Inc., 284 F.2d 599 (D.C. Cir. 1960); LiveUniverse, Inc. v. MySpace, Inc., Case No. CV 06-6994 (C.D. Cal. 2007); N.Y. Mercantile Exch., Inc. v. IntercontinentalExchange, Inc., 323 F. Supp. 2d 559 (S.D.N.Y. 2004).

[11] United States v. Visa U.S.A., Inc., 163 F. Supp. 2d 322, 379 (S.D.N.Y. 2001).

[12] See Tim Wu & C.S. Yoo, *Keeping the Internet Neutral?: Tim Wu and Christopher Yoo Debate*, 59 FED. COMM. L.J. 575 (2007); C.S. Yoo, *Network Neutrality, Consumers, and Innovation*, U.CHIC. LEGAL F. (forthcoming 2008); C.S. Yoo, *Beyond Network Neutrality*, 19 HARV. J. ON L. & TECH. 1 (2005).

costs, making customers subject to increases in the prices of service and replacement parts.[13]

George Priest argues that antitrust law and policy should take into account the economic theory of networks.[14] He suggests that network effects should guide a new interpretation of such antitrust cases as *Visa/MasterCard*, *American Airlines*, *BMI/ASCAP*, *NCAA*, *Associated Press*, and *Dr. Miles*. Most closely related to technology lock-in, Priest contends that *Radiant Burners* and modern telecommunications cases such as *Terminal Railroad* and *Trinko* should be examined in terms of technological interoperability within a network.

This article extends to technology lock-in the discussion of network effects that I presented earlier.[15] For additional discussion of legal and regulatory aspects of access to networks, see work by Spulber and Yoo.[16] Sidak and Spulber discuss legal and economic dimensions of deregulation in network industries.[17] The article builds on path-breaking work by Stanley J. Liebowitz and Stephen E. Margolis.[18] They present critiques of the discussions of network externalities and technology lock-in that are related closely to the present analysis. The notion of technology lock-in is closely related to the broader concept of "path dependence" advanced by some economic historians.

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[13] 540 U.S. 451 (1992).

[14] G.L. Priest, *Rethinking Antitrust Law in an Age of Network Industries*, John M. Olin Center for Studies in Law, Economics, and Public Policy, Research Paper No. 352, Yale Law School (2007).

[15] D.F. Spulber, *Consumer Coordination in the Small and in the Large: Implications for Antitrust in Markets with Network Effects*, 4 J. COMPETITION L. & ECON. 1 (June 2008).

[16] D.F. Spulber & C.S. Yoo, *Access to Networks: Economic and Constitution Connections*, 88 CORNELL L. REV. 885 (2003); D.F. Spulber & C.S. Yoo, *Network Regulation: The Many Faces of Access*, 1 (4) J. COMPETITION L. & ECON. 645 (December 2005); D.F. Spulber & C.S. Yoo, *On the Regulation of Networks as Complex Systems: A Graph Theory Approach*, 99 NW. U. L. R. 1687 (2005); D.F. Spulber & C.S. Yoo, *Mandating Access to Telecom and the Internet: The Hidden Side of* Trinko, 107 COLUM. L. REV. 1822 (2007); D.F. Spulber & C.S. Yoo, NETWORKS IN TELECOMMUNICATIONS: ECONOMICS AND LAW, (Cambridge: Cambridge University Press 2007).

[17] J.G. Sidak & D.F. Spulber, *The Tragedy of the Telecommons: Government Pricing of Unbundled Network Elements Under the Telecommunications Act of 1996*, 97 COLUM. L. REV.1201 (1997); J.G. Sidak & D.F. Spulber, *Network Access Pricing and Deregulation*, 6:4 INDUS. & CORP. CHANGE 757 (1997); J.G. Sidak & D.F. Spulber, DEREGULATORY TAKINGS AND THE REGULATORY CONTRACT: THE COMPETITIVE TRANSFORMATION OF NETWORK INDUSTRIES IN THE UNITED STATES (Cambridge: Cambridge University Press 1997); J.G. Sidak & D.F. Spulber, *Deregulation and Managed Competition in Network Industries*, 15 YALE J. ON REG. 117 (1998); J.G. Sidak & D.F. Spulber, *Cyberjam: Internet Congestion of the Telephone Network*, 21(2) HARV. J. L. & PUB. POL'Y 327 (1998).

[18] S.J. Liebowitz & S.E. Margolis, *Network Externality: An Uncommon Tragedy*, 8 J.ECON. PERSP. 133 (1994); S.J. Liebowitz & S.E. Margolis, *Path Dependence, Lock-in and History*, 11 J.L., ECON. & ORG. 205 (1995); S.J. Liebowitz & S.E. Margolis, *Are Network Externalities a New Source of Market Failure?*, 17 RES. L. & ECON. 1 (1995); S.J. Liebowitz & S.E. Margolis, *Market Processes and the Selection of Standards*, 9 HARV. J.L. & TECH. 283 (1996); S.J. Liebowitz, & S.E. Margolis, *Network Effects*, *in* HANDBOOK OF TELECOMMUNICATIONS ECONOMICS (M.E. Cave et al., eds., Amsterdam: Elsevier Science, vol. 1 2002).

Stanley Liebowitz and Stephen Margolis point out that economies may be "path dependent" in benign ways.[19] Dependence on initial conditions exists in many economic situations that are consistent with optimizing behavior. For example, investment by a firm can depend on its initial capital stock, particularly in the presence of adjustment costs. In addition, optimization decisions made under uncertainty depend on the information available at the time that the decision is made. These forms of "path dependence" are present in any type of dynamic decision making. As Liebowitz and Margolis demonstrate, the "path dependence" that corresponds to technology lock-in "suppresses the feasibility, in principle, of improvements in the path." In other words, the market is on the wrong path but it is assumed that the government is capable of both discerning the right path and taking appropriate policy actions to correct the market failure.[20]

The discussion is organized as follows. Section II shows that the concept of technology lock-in rests on the underlying assumption of network effects. Sections III–V examine the three major factors that limit technology lock-in. Consumer coordination captures the benefits of network effects hence eliminating this potential cause of technology lock-in. Because network effects tend to be confined to the ICT and selected electronics industries, interactions between network effects and technology adoption also will be confined to these specific industries. Firms in network industries have incentives to pursue interconnection and interoperability when it is efficient to do so. Finally, Section VI considers implications for antitrust policy that result from rejecting the concept of technology lock-in.

II. NETWORK EFFECTS AND TECHNOLOGY LOCK-IN

The concept of technology lock-in is based on underlying network effects. It bears emphasis that the presence of "network effects" in economic models is an *assumption*, not a result of economic analysis. This section examines how the network effects assumption results in predictions of technology lock-in.

A. The Network Effects Assumption

The network effects assumption is the foundation of economic models of technology lock-in. The discussion in this section is not meant as a criticism of these interesting and important economic analyses. Rather the discussion

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[19] S.J. Liebowitz & S.E. Margolis, *Path Dependence, Lock-in, and History*, 11 J.L., ECON. & ORG. 205 (April 1995).

[20] Liebowitz and Margolis refer to optimization based on initial conditions as "first-degree path dependence." Liebowitz and Margolis refer to optimization under uncertainty based on available information as "second-degree path dependence." Liebowitz and Margolis refer to the assumption that markets make incorrect choices in technology that governments can correct as "third-degree path dependence." *Id.*

is intended to distinguish assumptions from conclusions to assist public policy makers in understanding the technology lock-in debate.

Katz and Shapiro distinguish between direct and indirect network effects.[21] A *direct network effect* refers to the effect of one person's consumption of the network good on another person's benefit obtained from the network good. An *indirect network effect* refers to the effect of prices and features of complementary goods on a consumer's benefit from the network good. Both types of network effects appear in technology lock-in arguments and in antitrust policy. The theoretical literature in economics on technology lock-in employs both types of network effects.

Katz and Shapiro, in their 1985 article on systems competition, assume that:

> an individual's consumption benefits will depend on the future size of the relevant network. Consumers will base their purchase decisions on expected network sizes.[22]

Katz and Shapiro, in their 1986 article on competing technologies, state the assumption that:

> The benefits that a consumer derives from consumption of one unit of the good depend on how many other consumers ultimately purchase compatible units, that is, units utilizing the same technology. In other words, the extent of consumption externalities depends only on the final network sizes.[23]

Katz and Shapiro, in their 1992 article on the decision to adopt a new technology when there is an installed base of another technology, assume that:

> Our demand structure is designed to focus on network externalities and consumers' choices between technologies.[24]

Farrell and Saloner, in their 1985 article on innovation, assume that there are "positive network externalities":

> whatever *j*'s choice, he prefers to have others make the same choice. This introduces the coordination considerations that are the focus of this article.[25]

Farrell and Saloner, in their 1986 article on innovation and installed base, assume that users of a technology derive benefits from the number of other users so that:

> The equilibrium outcome depends on the size of the installed base when the new technology is introduced, how quickly the network benefits of the new technology are realized, and the relative superiority of the new technology.[26]

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[21] M.L. Katz & C. Shapiro, *Systems Competition and Network Effects*, 8 J. ECON. PERSP. 93 (1994).

[22] M.L. Katz & C. Shapiro, *Network Externalities, Competition, and Compatibility*, 75 AM. ECON. REV. 424, 426 (June 1985).

[23] M.L. Katz & C. Shapiro, *Technology Adoption in the Presence of Network Externalities*, 94 J. POL. ECON. 822, 826 (August 1986).

[24] M.L. Katz & C. Shapiro, *Product Introduction with Network Externalities*, 40 J. INDUS. ECON. 55, 58 (March 1992).

[25] J. Farrell & G. Saloner, *Standardization, Compatibility, and Innovation*, 16 RAND J. ECON. 70, 73 (1985).

[26] J. Farrell & G. Saloner, *Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation*, 76 AM. ECON. REV. 940, 941 (December 1986).

Farrell and Saloner, in their 1992 article on technological compatibility, allow for product variety but assume that there are network externalities:

> While each buyer has a locational preference for one of the technologies over the other, his utility is also increasing in the number of other users with whom his product is compatible.[27]

Choi and Thum attribute inefficient timing of adoption decisions to the assumed presence of "network externalities." [28]

W. Brian Arthur, in his 1989 article on technology lock-in, assumes that:

> The version of [technology] A or B each agent chooses is fixed or frozen in design at his time of choice, so that his payoff is affected only by past adoptions of his chosen technology.[29]

Technology lock-in also is known as "path dependence." What Arthur refers to as "increasing returns to adoption" is when each consumer's payoff is increasing in the number of past adoptions. This definition thus corresponds to network effects from prior consumption of the network good. This approach is also followed by Robin Cowan in his 1991 article on technology adoption, which assumes that:

> Two technologies, A and B, are available for performing the same task and both are subject to increasing returns to adoption . . . for each technology the net benefit to the next adopter increases with the number of previous adopters of that technology.[30]

Farrell and Klemperer, in a survey of the literature, state the assumption that network effects affect technology choice between competing technologies A and B as follows:

> Network effects are strong if they outweigh each adopter's preferences for A versus B, so that each prefers to do whatever others do. Then "all adopt A" and "all adopt B" are both Nash equilibria of the simultaneous-move noncooperative game . . . Strong network effects thus create multiple equilibria if adoption is simultaneous (not literally, but in the game-theoretic sense that players cannot react to others' actual choices but must base their actions on expectations).[31]

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[27] J. Farrell & G. Saloner, *Converters, Compatibility, and the Control of Interfaces*, 40 J. INDUS. ECON. 9 (March 1992).

[28] J.P. Choi & M. Thum, *Market Structure and the Timing of Technology Adoption With Network Externalities*, 42 EUR. ECON. REV. 225 (1989).

[29] *See* B. Arthur, *Competing Technologies, Increasing Returns, and Lock-in by Historical Events*, 97 ECON. J. 116, 117 (1989); *see also* B. Arthur, *Positive Feedbacks in the Economy*, 262 SCI. AM. 92 (February 1990); B. Arthur (1994), *supra* note 2.

[30] R. Cowan, *Tortoises and Hares: Choice Among Technologies of Unknown Merit*, 101 ECON. J. 801, 801–814 (July 1991).

[31] J. Farrell & P. Klemperer, *Coordination and Lock-in: Competition with Switching Costs and Network Effects*, HANDBOOK OF INDUSTRIAL ORGANIZATION (Berkeley, CA: University of California, Berkeley 2006).

As Farrell and Klemperer observe, if consumer preferences are similar, strong network effects still are not a problem because the efficient outcome is an equilibrium. Communication, side payments, and commitment to a technology will address the problem, as they point out. If consumer preferences differ, then strong network effects can lead to inefficient technology adoption. In this way, the strong network effects assumption forces technology adoption by consumers to depend on their ability to coordinate their decisions.

If network effects were not sufficiently strong that they outweigh individual preferences, market outcomes would tend to be efficient. Consumer choices in the marketplace would reflect their relative preferences for goods. This would eliminate the technology lock-in problem.

B. Representation of Network Effects and Technology Adoption

Network effects refer to the mutual benefits that consumers receive when they consume the same good. The basic issues can be illustrated formally for the case of two consumers, each of whom consumes a network good. Let q^1 and q^2 denote the quantity of consumption of the two consumers. Each of the consumers derives a benefit from his own consumption of the network good and from the consumption of the other consumer. Let u^1 and u^2 denote the utility received by the two consumers. Then, with mutual benefits of consumption, the utility functions of consumer 1 and consumer 2 are as follows:

$$u^1 = u^1(q^1, q^2), \quad \text{and} \quad u^2 = u^2(q^2, q^1).$$

Each consumer's utility function is increasing in his own consumption, as is standard. Each consumer's utility also is increasing in the other consumer's consumption. This is the "direct network effect" that is discussed in the economics literature.

Liebowitz and Margolis demonstrate that direct and indirect network effects have substantially different economic implications.[32] The concept of indirect network effects corresponds to an earlier notion of pecuniary externalities dating back to Pigou. Yet, indirect network effects do not correspond to the market failure of network externalities. Transactions between consumers and firms involving complementary products entirely internalize the benefits of consuming complementary goods. Accordingly, despite frequent claims to the contrary, indirect network effects cannot be a source of market failure leading to technology lock-in.

Economists typically abstract from the basic model of interdependent demand in two ways. First, they assume that the volume of information does

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[32] Liebowitz & Margolis (1994) & (2002), *supra* note 5.

not matter, so that all subscriptions to the network represent the same amount of consumption of network services. For example, Rohlfs and Artle and Averous assume that consumers derive benefits only from their own and others' membership.[33] In the formal model of network effects, this means the following. If consumer i consumes the network services, then his level of consumption is indicated by $q^i = 1$. If consumer i does not consume the network services, then his level of consumption is indicated by $q^i = 0$. Here, the index i refers to consumer 1 and to consumer 2.

The second abstraction that is typical in the network effects literature is that the identity of subscribers to the network does not matter, only the number of subscribers. It is assumed that there are many consumers described by an index i. The index i now is continuous and takes values on the interval $[0, N]$ where N is the total population of consumers. Suppose that n consumers decide to consume the network good.[34]

Combining these two abstractions yields the canonical model of network effects in economics. The benefit of a consumer i who joins the network depends on the number of network subscribers. In addition, the consumer types can be ordered so that as the consumer's type i increases the consumer's benefit decreases. The marginal consumer will have benefits greater than or equal to the price of the network good.

The benefit of an individual consumer i can be represented as the sum of a common network effect and idiosyncratic consumption effect,

$$u(n, i) = g(n) - h(i).$$

The function $g(n)$ is the network effect, which is increasing in the number of consumers that consume the network good. The presence of this function is the critical "network effects" assumption.

The function $h(i)$ represents the idiosyncratic consumption effect.[35] Consumer types i can be ordered such that higher types i have a higher $h(i)$,

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[33] *See* J. Rohlfs, *A Theory of Interdependent Demand for a Communications Service*, 5 BELL J. ECON. & MGMT. SCI. 16 (1974). Artle and Averous examine interdependent demand in communications based on the number of subscribers. *See* R. Artle & C. Averous, *The Telephone System as a Public Good: Static and Dynamic Aspects*, 4 BELL J. ECON. & MGMT. SCI. 89 (1973). On network effects, see also N. Economides, *The Economics of Networks*, 14 INT'L J. INDUS. ORG. 673 (Mar. 1996), N. Economides & C. Himmelberg, *Critical Mass and Network Evolution in Telecommunications*, *in* TOWARD A COMPETITIVE TELECOMMUNICATIONS INDUSTRY: SELECTED PAPERS FROM THE 1994 TELECOMMUNICATIONS POLICY RESEARCH CONFERENCE (Gerard Brock ed., Mahwah, NJ: Lawrence Erlbaum Associates 1995).

[34] The number of subscribers is less than or equal to the population, $n \leq N$. The number of subscribers aggregates consumption decisions so that the total demand for the network equals $n = \int_0^N q^i \, \mathrm{d}i$.

[35] The additively separable form is for purposes of exposition and allows for a clear discussion of the main issues. The discussion can be generalized to allow for different functional forms, but this would complicate the discussion unnecessarily. Let $g(n)$ be increasing and concave in n, $g'(n) > 0$ and $g''(n) < 0$. Let $h(i)$ be increasing and (weakly) convex in i, $h'(i) > 0$ and

and thus a lower benefit from consuming the network good. This ordering is without loss of generality in the representation of the consumers' preferences.[36]

An equilibrium is said to exist when the number of consumers who adopt the good is consistent with the marginal consumer's decision. The number of consumers who adopt the network good is n^*. The marginal consumer then has the idiosyncratic preference parameter $i = n^*$. For the equilibrium number of consumers to be consistent with the marginal consumer requires that the marginal consumer's benefit exactly equals the price of the network good,

$$g(n^*) - h(n^*) = p.$$

The number of consumers n^* represents the total demand for the network good. This is shown in Figure 1.

Suppose that consumers make their product purchase decisions without prior agreements and without monetary transfers. Then, the market equilibrium demand n^* can be characterized as a Nash noncooperative equilibrium. Each consumer's decision whether or not to purchase the network good is a best response to the equilibrium decisions of other consumers.

There may be multiple Nash equilibria. There may be a "zero-output trap," because a consumer's best response to no one joining the network is also to not join the network. Because there are network effects, the consumer does not benefit from the network good if no one else joins. There also can be low-output and high-output Nash equilibria. The marginal consumer condition can have multiple solutions. For example, there might be three Nash equilibria as shown in Figure 2. The figure depicts the zero-output equilibrium, $n = 0$, the low-output equilibrium, n_L, and the high-output equilibrium, n_H.[37]

Any of these Nash equilibria is a possible outcome of the noncooperative game. This does not imply that any particular equilibrium actually occurs as the outcome of the consumers' demand game. There is no way of sorting through the Nash equilibria without some sort of coordination between consumers. There is also no theoretical guarantee that consumers would reach even a Nash equilibrium in such a game. The Nash equilibrium only provides a statement about what best responses are consistent. With multiple

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$h''(i) \geq 0$. Let $g(0) = 0$ because network effects require some participation. Normalize h such that $h(0) = 0$.

[36] For any given price, p, of the network good, a type i consumer adopts the good if his benefits are greater than or equal to the price, $g(n) - h(i) \geq p$. If a consumer i adopts the network good, all consumers with lower types also will adopt the network good. The marginal consumer exhausts all net benefits, $g(n) - h(i) = p$.

[37] The function $g(n) - h(n)$ is u-shaped because $g(n)$ is increasing and concave and $h(n)$ is increasing and (weakly) convex.

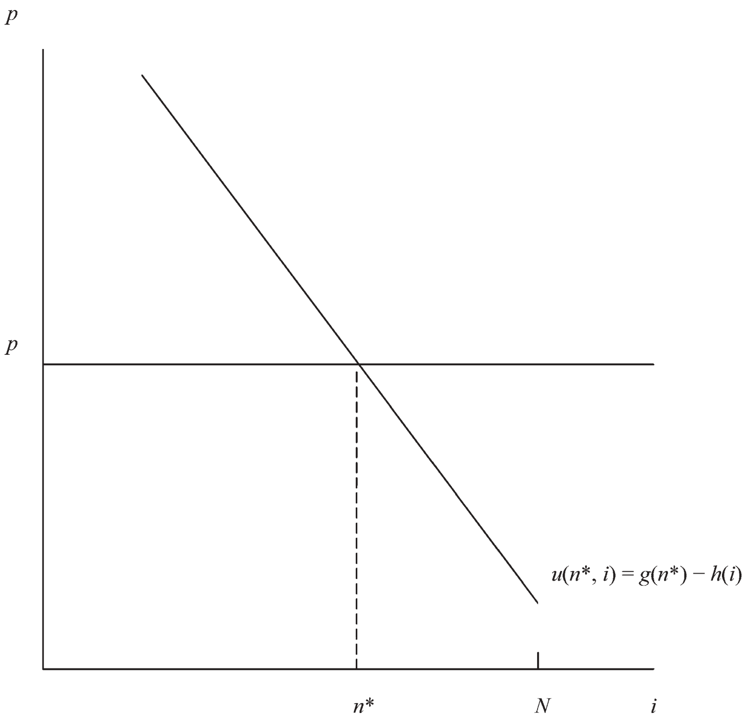

Figure 1. The marginal consumer's type equals the number of consumers who buy the network good at the Nash equilibrium n^*, given the price p.

Nash equilibria, predictions about the outcome of the game require additional rules or institutions.

The economics literature transposes the basic model of network effects to technology choice. Rather than consider whether or not to join a network, consumers choose between two competing technologies. The two technologies A and B both are goods that exhibit network effects. Thus, the benefit of an individual consumer i differs for the two technologies:

$$u^A(n,i) = g^A(n) - h^A(i), \quad \text{and} \quad u^B(n,i) = g^B(n) - h^B(i)$$

Of course, there is no reason to expect that any technology should exhibit network effects unless the technology is a network good. Accordingly, network effects are built into the technology choice model by assumption.

The basic coordination problem is driven by the standard prisoners' dilemma problem that is familiar to game theorists. As posed by Farrell and Klemperer, the coordination problem is represented in Table 1.[38]

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[38] *See* Farrell & Klemperer, *supra* note 31. Here, h^{ij} refers to the idiosyncratic preferences of a member of group $i = 1, 2$ with regard to technology $j = A, B$.

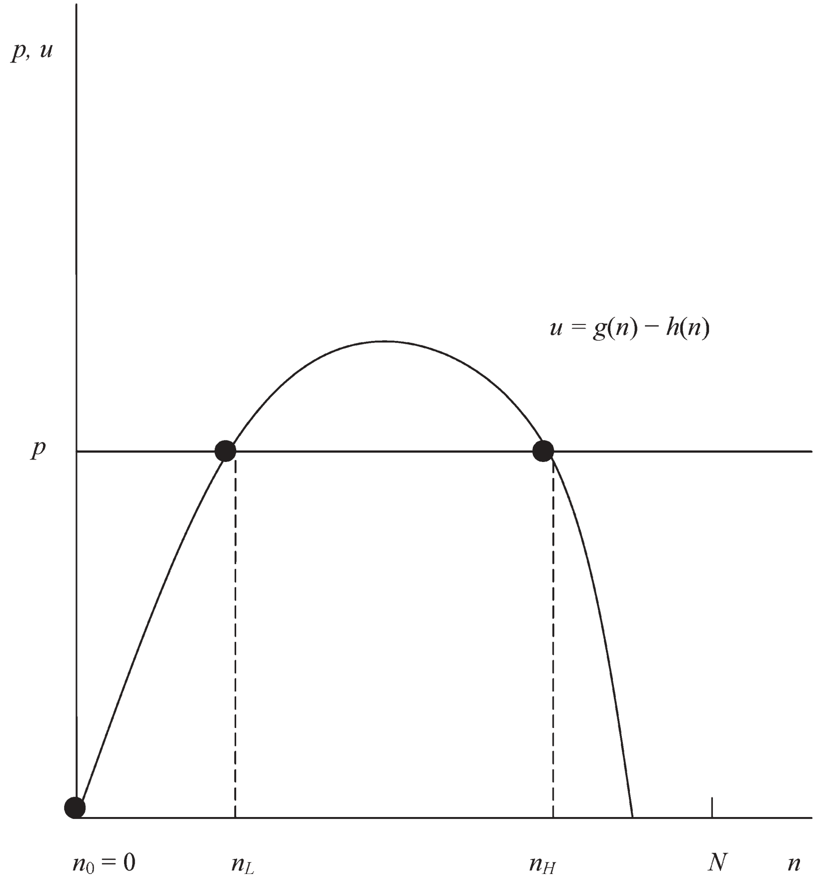

Figure 2. A network effects example with three Nash equilibria for a given price p, n_0, n_2, and n_{H}.

Treating each group as a single player, the population of consumers is partitioned into two groups, with N_1 consumers in the first group and N_2 consumers in the second group. As emphasized previously, Farrell and Klemperer assume that strong network effects override any idiosyncratic preference effects.[39] Then there will be two Nash equilibria, one in which both groups adopt technology A and one in which both groups adopt technology B.

There exists a tension between network effects and idiosyncratic preferences. One Nash equilibrium Pareto dominates the other when the two groups agree on the best technology. This means that group 1 and group 2

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[39] Formally, this assumption requires that members of group 1 prefer the technology that others adopt, $g^A(N_1 + N_2) - h^{1A} > g^B(N_1) - h^{1B}$, and $g^B(N_1 + N_2) - h^{1B} > g^A(N_1) - h^{1A}$. The same holds for members of group 2, $g^A(N_1 + N_2) - h^{2A} > g^B(N_2) - h^{2B}$, and $g^B(N_1 + N_2) - h^{2B} > g^A(N_2) - h^{2A}$.

Table 1. The Per-consumer Payoffs for the Technology Adoption Game with Common Network Effects and Idiosyncratic Preferences with Two Groups of Consumers

	Group 2	
Group 1	Adopt technology A	Adopt technology B
Adopt technology A	$g^A (N_1 + N_2) - h^{1A}, g^A (N_1 + N_2) - h^{2A}$	$g^A (N_1) - h^{1A}, g^B (N_2) - h^{2B}$
Adopt technology B	$g^B (N_1) - h^{1B}, g^A (N_2) - h^{2A}$	$g^B (N_1 + N_2) - h^{1B}$, $g^B (N_1 + N_2) - h^{2B}$

are each better off if everyone adopts technology A rather than B.[40] Then, the game becomes a "ranked coordination game with one equilibrium Pareto dominating the other." If both network effects and idiosyncratic preference effects matter, the adoption game becomes more complex. For example, group 1 may be better off if everyone adopts technology A rather than B and group 2 may be better off if everyone adopts technology B rather than A.[41] The Pareto criterion does not allow for a comparison of the two Nash equilibria because switching between equilibria makes one group better off and the other group worse off.

Consider the technology lock-in problem when there are many consumers. Again, discussions of lock-in assume that network effects drive the economy. Consider Arthur's dynamic version of technology lock-in. Arthur's argument assumes that one technology has an advantage if there is a small number of consumers whereas the other technology has an advantage if there is a large number of consumers. Arthur further assumes that consumers cannot communicate with each other to coordinate their adoption decisions. Also, consumers are fully myopic in that their technology adoption choices depend only on past adoptions, without any expectations of future adoption. Consumers behave in a myopic manner because the benefits that they receive from network effects are only those from previous adopters. Thus, consumers initially adopt the technology that offers benefits with few consumers. Consumers who arrive later continue to adopt that technology as benefits grow further with additional subscribers. As a consequence, many consumers adopt the technology that offers greater benefits for only a few adopters. The outcome is inefficient because the consumers missed choosing the technology that offered greater benefits for a large number of consumers.

Our formal representation of network effects can be applied to illustrate Arthur's lock-in story. Let $g^A(n)$ and $g^B(n)$ represent the common network effects of two technologies. Technology B offers greater benefits with small

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[40] Formally, this assumption means that for members of group 1, $g^A(N_1 + N_2) - h^{1A} > g^B(N_1 + N_2) - h^{1B}$, and for members of group 2, $g^A(N_1 + N_2) - h^{2A} > g^B(N_1 + N_2) - h^{2B}$.

[41] Formally, this assumption means that for members of group 1, $g^A(N_1 + N_2) - h^{1A} > g^B(N_1 + N_2) - h^{1B}$, and for members of group 2, $g^A(N_1 + N_2) - h^{2A} < g^B(N_1 + N_2) - h^{2B}$.

numbers of adopters whereas technology *A* offers greater benefits for large numbers of adopters. The critical crossing point occurs at $\tilde{n}$, see Figure 3. Assuming that the total number of consumers who could adopt the technology is greater than the critical crossing point, then technology *A* would be the most efficient.

Path dependence in Arthur's model thus relies on consumer myopia and an absence of even tacit coordination. The first few consumers adopt technology *B* because benefits are greater with few consumers. The next adopters always prefer technology *B* because it has increasing benefits due to network effects so that the benefits of *B* to the marginal consumer of *B* will always exceed the benefits of the first consumer adopting technology *A*, which equals zero. This is also true if a few consumers can coordinate their adoption decisions because the benefits of technology *B* grow with each set of adopters and the benefits for the first few adopters of technology *A* remain at the same low level. The path of adoption that is described by the path-dependence story is thus movement along the $g^B(n)$ curve as adoptions and network benefits increase over time.

In Arthur's framework, consumers only derive network-effects benefits from prior adopters – not future ones. Consumers act myopically

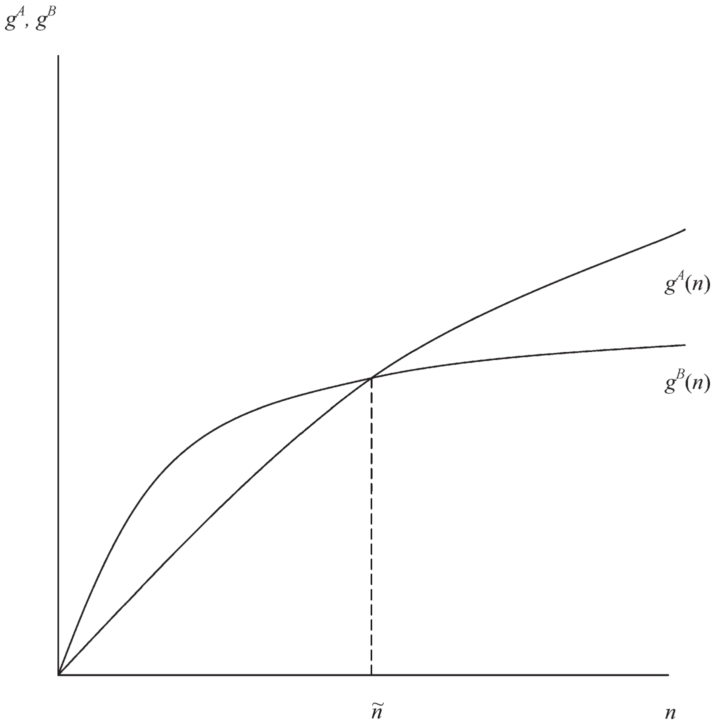

Figure 3. Technology *B* offers greater network benefits with few consumers whereas technology *A* offers greater network benefits with many consumers.

by assumption. It should not be surprising that a technology that offers greater benefits for early adopters would be the one adopted by myopic consumers. The logic is purely circular; myopic adopters behave myopically. When consumers benefit from future adopters, they will form expectations about the behavior of those adopters and make their decisions accordingly.

III. CONSUMER COORDINATION AND ADOPTION OF INNOVATIONS

This section considers how consumer coordination both in the small and in the large addresses the problem of technology lock-in. With consumer coordination of technology adoption choices, the network effects problem is addressed. Then, consumers can make efficient technology adoption decisions. When the number of consumers is small, consumers can coordinate their adoption decisions efficiently. When the number of consumers is large, firms offering the technology can help consumers coordinate their technology adoption decisions.

A. Consumer Coordination in the Small and Adoption of Innovations

Technology lock-in depends on the underlying assumption that there are network effects, which result from the social benefits of technology adoption. The consumers face a problem of social benefits because they do not take into account the benefits that their technology adoption choices would confer on other potential adopters. Ronald Coase analyzed the closely related problem of negative externalities in his classic work on the problem of social cost.[42] He argued that, with small numbers of consumers, low transaction costs, and well-defined property rights, bargaining would lead to an efficient outcome. Coasian bargaining has important implications for the problem of technology adoption.

This section refers to coordination with small numbers of consumers. I refer to bargaining with small numbers of consumers as "coordination in the small." The preconditions for efficiency discussed by Coase for negative externalities are more likely to exist in the case of network externalities, that is, transaction costs are low and property rights are well-defined.

With network effects and small numbers of consumers, transaction costs of bargaining are likely to be low. Consumers who will benefit from network effects are likely to be connected by family, friendship, business, or other social relationships. Consumers obtain benefits from network effects often because they wish to communicate with those with whom they already have relationships. Such relationships form a basis for agreeing to subscribe to the same communications network.

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[42] R.H. Coase, *The Problem of Social Cost*, 3 J.L. & ECON. 1 (1960).

Consumers who benefit most from exchanging information in the small numbers case are those with close social ties. They obtain network benefits from subscribing to a telecommunications network to maintain those social ties. Consumers wish to exchange documents, photos, videos, and other information with those with whom they already are connected. Catherine Tucker finds that potential adopters of video-messaging systems within a firm only react to adoption by those people with whom they wish to communicate.[43]

Transaction costs should be lowered because the consumers seeking to coordinate are not in an adversarial relationship. Because potential adopters of virtual or physical network goods already have a cooperative relationship, transaction costs should be low. Also, because the negotiation deals with mutual benefits, the negotiation itself will not be adversarial, further lowering the potential costs of negotiation. In pollution abatement, enforcement may be needed to make sure that pollution is reduced and that transfer payments are made. Coordination does not require outside enforcement, because both sides have an incentive to adopt the technology that they have agreed upon. Adoption of the technology is easily observed by both parties, so monitoring costs are minimal. Transfer payments may not be needed because the adoption is mutually beneficial.

Coase's condition that property rights should be well-defined is meant to apply to pollution abatement, where either the polluter or the recipient of pollution has property rights. Such an issue does not arise in the case of network effects. Network effects are bilateral, both sides obtain benefits, so no assignment of property rights is necessary. Agreement to coordinate adoption yields benefits to both sides, which provides the motivation for coordination without any assignment of rights.

Farrell and Klemperer argue based on case studies that efficient equilibria need not be realized. Consumers may be "confused" due to imperfect information about other players' strategies. Alternatively, "splintering" may occur if individuals cannot coordinate within groups. There may be many equilibria that involve splintering. These equilibria are not "coalition-proof" because individuals would benefit by forming coalitions to take advantage of network effects. Farrell and Klemperer further observe that consumers may coordinate on the wrong equilibrium. In the technology adoption game, technology B may be Pareto inferior to A, but the two groups may coordinate internally and interact with the other group to choose technology B due to expectations about which technology will be successful. Alternatively, the groups may choose the inferior technology due to imperfect rules of thumb used for coordination.

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[43] C. Tucker, *Interactive, Option-Value and Domino Network Effects in Technology Adoption* (MIT, Sloan, Working Paper, February 2006).

Consider again the technology adoption game in Table 1 where network effects are strong. With small numbers of consumers and low transaction costs, efficient bargaining will solve the coordination problem. Suppose that the two groups of consumers agree on what is the best technology. Then, the game of technology choice with strong network effects is a "ranked coordination game." If consumers can communicate they will choose the best equilibrium, and they will reach the equilibrium without the need for monetary transfers. The consumers will agree to select the best technology and only the most efficient technology will be adopted. Splitting and out-of-equilibrium outcomes will be avoided. Policy makers should treat the small numbers situation carefully because there should be a presumption that consumer coordination can address effectively the benefits of network effects.

Next, consider the technology adoption game in Table 1 where network effects are strong and differences in idiosyncratic preferences imply that the two equilibria cannot be Pareto-ranked. The adoption game presents a quandary because communication alone is not sufficient to resolve the impasse. When monetary transfers are feasible, consumers will achieve the outcome that yields the greatest total surplus by making compensatory transfers to the group that would prefer the less desirable technology. If monetary transfers are not feasible, the two groups must find a way to choose between the two Nash equilibria.

Sequential adoption selects a single Nash equilibrium. Idiosyncratic preference effects change the nature of the sequential technology adoption game. In the game shown in Table 1, the first mover determines the outcome of the game. When consumers disagree on the best technology, group 1 as first mover would adopt technology A and group 2 would then also adopt A because network effects override idiosyncratic preference effects. Group 2 as first mover would adopt technology B, and group 1 would follow by adopting technology B. As a result, each group is made better off if it moves first. The sequential technology adoption game is a simplified version of the framework presented by Farrell and Saloner. They consider a game in which one of the technologies is available and adopted before the other, and users decide whether or not to switch to the new technology. If the new technology is preferred by all when everyone adopts, the unique sequential equilibrium involves all users switching to the new technology.[44]

Whether or not the two Nash equilibria are Pareto-ranked, sequential adoption addresses network effects and solves the technology lock-in problem.

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[44] Farrell and Saloner (1985) find that, with asymmetric information, the equilibrium of the adoption game fails to be Pareto efficient when users cannot communicate. Allowing some communication eliminates such excess inertia when preferences coincide but increases it when preferences differ.

The assumption of strong network effects implies that either group knows that by adopting one of the technologies, the other group will get on the bandwagon, thus achieving coordination without prior communication.[45] Then, if either group is a first mover, they will adopt technology A and the follower will choose to adopt technology A as the best response. In this way, sequential adoption results in the Pareto-dominant outcome.

The efficiency criterion itself raises an issue for public policy. In the absence of monetary transfers between consumers, the Pareto criterion is appealing for evaluating the efficiency of technology markets. The two welfare theorems of neoclassical economies apply the Pareto criterion to the study of product markets. In considering the neoclassical general equilibrium setting, it is worthwhile to recognize the possibility of multiple market equilibria.

Total consumers' surplus is another effective criterion.[46] Maximizing total surplus implicitly involves the possibility of monetary transfers between consumers. The total surplus criterion for efficiency generally differs from the Pareto criterion. Applying a total surplus efficiency criterion distinguishes between the two equilibria depending on the relative levels of total surplus.[47] Although the total benefits approach is highly useful in a variety of contexts, it has limited value in the present evaluation of technology adoption decisions. One of the technologies will most likely yield greater surplus.

To interpret the lower surplus outcome as representing inefficiency imposes a tough standard on technology adoption decisions. Consumers would not only need to coordinate their adoption decisions. They would need to make agreements involving compensating monetary transfers. This would certainly be of limited value as a guide to public policy. Government agencies would not have sufficient information to determine which technology generates the greatest consumers' surplus. Doing so would require not only measuring idiosyncratic preference effects but also determining the benefits of network effects. Moreover, providing incentives for consumers to adopt the desired technology when private transfers are not feasible would require government mandates of technology choices, or worse yet, public monetary transfers. When private transfers are not feasible and public transfers are not desirable, the Pareto criterion seems more useful for evaluating technology adoption decisions. The Pareto criterion is better suited for evaluating consumer decisions in a strategic setting with multiple equilibria.

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[45] *See* J. Farrell & G. Saloner, *Standardization, Compatibility, and Innovation*, 16 RAND J. ECON. 70 (1985).

[46] This means comparing $(N_1 + N_2)g^A(N_1 + N_2) - N_1h^{1A} - N_2h^{2A}$ versus $(N_1 + N_2)g^B(N_1 + N_2) - N_1h^{1B} - N_2h^{2B}$.

[47] Farrell and Saloner (1985, 1986) apply a total surplus criterion in defining "excess inertia." They add the benefits of new adopters and those of the installed base. They state that "the installed base may cause excess inertia" (1986, p. 942).

B. Consumer Coordination in the Large and Adoption of Innovations

When there is a large number of consumers, it becomes more difficult for consumers to coordinate their technology adoption decisions. However, there are market mechanisms for coordination. Firms can act as intermediaries that provide instruments of coordination.

Friedrich Hayek referred to such coordination by firms as "spontaneous order."[48] Instruments of coordination not only include prices, but also mass marketing, mass media, and mass distribution. Through their marketing and sales efforts, firms help consumers make choices and learn about the choices of others. This is instrumental in overcoming the potential lack of coordination that concerns advocates of network effects.

If a firm owns a particular technology, it has economic incentives to promote the technology. The firm will invest in assisting consumers in coordinating their adoption decisions. F. Scott Kieff points out that intellectual property rights can facilitate coordination.[49] Even if the technology is not owned by an individual firm, intermediaries will have incentives to enter the market to assist consumers with coordination. For example, firms can provide customer services that are complementary to open source software, thus promoting the adoption of a particular type of open source software. Thus, even in the absence of technology ownership, there are economic incentives for firms to help consumers coordinate their adoption decisions.

Instruments of coordination provided by firms increase the information available to consumers. As a result, consumers are no longer playing a simple Nash noncooperative game. Rather, consumers have additional information about the choices of others. With sufficient information, consumers can coordinate in more sophisticated ways, such as choosing between noncooperative equilibria to select a Pareto-dominant outcome.

To illustrate coordination with many consumers, consider again Arthur's path dependence model. Suppose as in his framework that technology B is better when there are few consumers and technology A is better when there are many consumers. Suppose also as does Arthur that the number of consumers is greater than the critical number of adopters so that technology A is indeed the best technology. Suppose in contrast to Arthur that consumers derive benefits from all present and future adoptions. Then, consumers would want to coordinate their adoption decisions so as to choose

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[48] *See* F.A. Hayek, *Spontaneous (Grown) Order and Organized ('Made') Order*, *in* MARKET, HIERARCHIES & NETWORKS: THE COORDINATION OF SOCIAL LIFE 293-301 (G. Thompson, J. Francis, R. Levacic & J. Mitchell eds, Sage Publications, London 1991); F.A. Hayek, LAW, LEGISLATION AND LIBERTY, VOLUME 2: THE MIRAGE OF SOCIAL JUSTICE (Chicago, IL: The University of Chicago Press 1976); F.A. Hayek, *The Creative Powers of a Free Civilization*, Essays on Individuality.

[49] F.S. Kieff, *Coordination, Property, and Intellectual Property: An Unconventional Approach to Anticompetitive Effects and Downstream Access*, 56 EMORY L.J. 327 (2006).

technology A instead of B. The Nash equilibrium decisions made by many consumers can be represented using the benefits of the marginal consumer for each of the technologies. These benefits are $g^A(n) - h(n)$ and $g^B(n) - h(n)$.

The benefits of the marginal consumer are shown in Figure 4. The benefits of the marginal consumer are greater for technology B than they are for technology A when the number of adopters is less than the critical number of consumers, $\tilde{n}$. Conversely, the benefits of the marginal consumer are greater for technology A than they are for technology B when the number of adopters is greater than $\tilde{n}$. Accordingly, it follows that the two curves cross at the critical number of consumers, $\tilde{n}$. Because network effects are separable, all inframarginal consumers rank the two technologies in the same way as does the marginal consumer. Accordingly, the equilibrium denoted by n_H^A Pareto dominates the other Nash equilibria. When consumers are able to coordinate their adoption decisions, they will choose the Pareto-dominant Nash equilibrium.

Consumer coordination has the important implication that some Nash equilibrium outcomes can be ruled out. The only Nash outcome consistent

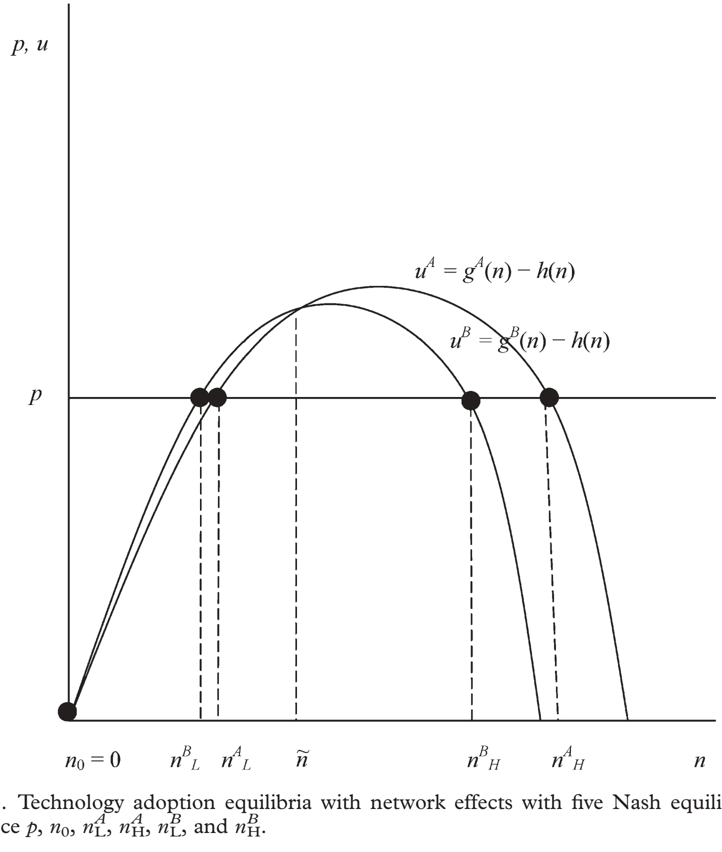

Figure 4. Technology adoption equilibria with network effects with five Nash equilibria for a given price p, n_0, n_L^A, n_H^A, n_L^B, and n_H^B.

with consumer coordination is the high-output Nash outcome. The reason is that there are consumers who stand to gain from joining the network at either the zero-output outcome or the low-output outcome. At the zero-output outcome, all of the consumers who benefit from the high-output outcome, n_H, would prefer to purchase the network good. All of these consumers receive a positive benefit (except the marginal consumer who is indifferent). This argues for consumer coordination to receive mutual benefits of consumption.

If the number of consumers n_H is small, they can enter into formal or informal agreements to join the network. If the number of consumers n_H is large, coordination between consumers must take place through mechanisms of spontaneous order. Groups of consumers with common interests band together to join the network. Mass marketing, mass media, mass communications, and other types of coordination stimulate consumers to choose the outcome that offers the greatest benefits to subscribers. Consumer coordination without side payments selects the high-output Nash equilibrium outcome. This is the only outcome that does not involve foregoing benefits.[50]

IV. POTENTIAL TECHNOLOGY LOCK-IN IS LARGELY CONFINED TO THE ICTE INDUSTRIES

In public policy discussions, "network goods" generally refer to information networks, which are confined to the ICTE industries. These industries have developed institutions that address interconnection and interoperability. These take advantage of network effects and thus limit the potential for technology lock-in that is attributed to network effects.

A. Physical and Virtual Networks

Although potential network effects are present throughout the economy, it is important to distinguish information networks from social, transaction, and transport networks. Although consumers experience mutual benefits of consumption in each of these types of networks, only information networks tend to raise policy concerns. What makes the ICTE industries the locus of potential network effects is the nature of the physical and virtual networks that connect economic actors. Information networks require coordination of consumption of network goods.

"Social networks" refer to the web of relationships between members of a society. Relationships include business, family, friends, ethnic groups,

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[50] For a comprehensive examination of network effects, see D.F. Spulber, *Consumer Coordination in the Small and in the Large; Implications For Antitrust in Markets With Network Effects*, J. COMPETITION L. & ECON. (forthcoming 2007).

religious affiliations, and interest groups. Mutual benefits of consumption arise from altruism in society and from caring about others in close personal relationships. These mutual benefits of consumption do not require consumption of the same network good and should not be interpreted as the network externality represented by network effects. In addition, members of a society follow fashions and experience bandwagon effects in many types of activities. These social phenomena should not be interpreted as the market failure described by network effects.

"Transaction networks" refer to markets in which buyers and sellers interact through decentralized transaction relationships and through centralized intermediaries.[51] Economic actors in transaction networks are connected by spot transactions, contracts, and other economic relationships. In decentralized exchange, buyers and sellers establish business relationships, find trading partners, and negotiate terms of exchange. In centralized exchange, intermediaries coordinate buyers and sellers through matchmaking and market making activities. Market making activities of intermediaries include aggregating demand and supply, clearing markets, discovering and adjusting prices, certifying quality, and providing liquidity and intermediary services. Examples of centralized-exchange intermediaries include organized exchanges for financial assets, securities, commodities, and currencies; business-to-business marketplaces, electronic commerce firms, auctioneers, market makers, and specialist firms; payment systems, and a great variety of brokers. The benefits of joining transaction networks should be internalized by the transactions that link economic actors.

"Transport networks" refer to physical network systems designed for travel and for transmitting various physical goods. Travel networks include bus, rail, shipping, and airline systems. Transportation networks also include utility transmission systems for electric power, natural gas, petroleum, and water. Transport systems include retail and wholesale networks for warehousing and transportation, postal sorting and delivery systems, and freight systems using various terminals and transportation modes. The benefits of forming transport networks are internalized by the firms that establish these networks.

"Information networks" involve the communication of data in a form that allows for computation. Information networks are critical to the policy debate over technology adoption. The definition of an information network derives from the general concept of an information system. "Information systems" comprise these two components: communication and computation. An industry definition of an information system states that

> 1. A system, whether automated or manual, that comprises people, machines, and/or methods organized to collect, process, transmit, and disseminate data that represent user

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[51] D.F. Spulber, *Firms and Networks in Two-Sided Markets*, *in* HANDBOOK IN INFORMATION SYSTEMS 137–200 (T. Hendershott ed., Amsterdam: Elsevier, vol. 1 2006).

> information. 2. Any telecommunications and/or computer related equipment or interconnected system or subsystems of equipment that is used in the acquisition, storage, manipulation, management, movement, control, display, switching, interchange, transmission, or reception of voice and/or data, and includes software, firmware, and hardware. . . . 3. The entire infrastructure, organization, personnel, and components for the collection, processing, storage, transmission, display, dissemination, and disposition of information.[52]

An information network connects economic actors by linking information systems. Accordingly, information networks require that the information that is exchanged is in a form that allows for communication and computation.

A network in which information can be exchanged and processed is said to exhibit interoperability.[53] The technical standards that allow for the creation of physical and virtual information networks require interoperability of software and hardware. Because of the key role played by interoperability, the discussion of network effects on technology adoption necessarily focuses on information networks.

The concept of interoperability is related to that of a platform, which refers to a collection of related technology standards. Platforms play an important role in information systems, both in communications and in computing. In computers, a platform is a "reconfigurable base of compatible components on which users build applications" and is identified with "engineering specifications for compatible hardware and software."[54] For example, IBM devised standards for the personal computer that were adapted by manufacturers of software designers, internal components, such as memory and microprocessors, and peripheral devices, such as printers and monitors.

In communications networks, platforms permit compatible transmission of information in communications and interconnection of transmission equipment.[55] Platforms in telecommunications include computer hardware

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[52] Committee T1A1, [renamed Network Performance, Reliability and Quality of Service Committee (PRQC)], 2000, *ATIS Telecom Glossary 2000*, Washington, DC: Alliance for Telecommunications Industry Solutions.

[53] The definition of interoperability is based on that of the Institute of Electrical and Electronics Engineers 1990, IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries, New York, NY.

[54] T. Bresnahan & S.M. Greenstein, *Technical Progress and Co-invention on Computing and in the Uses of Computers*, *in* BROOKINGS PAPERS ON ECONOMIC ACTIVITY: MICROECONOMICS 1–78 (Brookings Institution Press 1997); T. Bresnahan & S.M. Greenstein, *Technological Competition and the Structure of the Computer Industry*, 47 J. INDUS. ECON. 1 (March 1999); S.M. Greenstein, *Industrial Economics and Strategy: Computing Platforms*, 18 IEEE Micro 43 (May–June 1998).

[55] D.F. Spulber & C.S. Yoo, *Network Regulation: The Many Faces of Access*, 1 (4) J. COMPETITION L. & ECON. 635 (December 2005); D.F. Spulber & C.S. Yoo, *On the Regulation of Networks as Complex Systems: A Graph Theory Approach*, 99 NW. U.L. REV. 1687 (2005); D.F. Spulber & C.S. Yoo, *Mandating Access to Telecom and the Internet: The Hidden Side of* Trinko, 107 COLUM. L. REV. 1822 (2007).

and software standards for computer-based switching and transmission systems. Platforms in communications include computer software standards such as the Transmission Control Protocol/Internet Protocol (TCP/IP) used for Internet communications between computers. A network is said to be *modular* or to exhibit an *open architecture* if most suppliers of complementary services can gain access to the network.

To characterize information networks, it is useful to apply some basic tools from the area of mathematics known as graph theory.[56] Graphs are sets of points and lines that connect some of those points to each other. The points are referred to as nodes and the lines are referred to as links. Networks are graphs in which numerical values are assigned to the links. Economic actors connect to the network at the nodes in the graph. The links that connect the nodes in a graph represent some important aspect of the relationship between those economic actors. The configuration of the set of nodes and links provides a representation of the architecture of the network.

Formally, a graph is a pair $G = (J, L)$ consisting of a set of nodes J and a set of links L that connect the nodes. For example, in Figure 5, the set of nodes is $J = \{1, 2, 3, 4\}$ and the set of links is $L = \{(1, 2), (3, 4), (1, 4)\}$. The numerical values of the links can represent such things as costs, benefits, and transmission capacity.

In the communications industries, firms establish physical transmission networks to provide communications services. Examples include traditional telecommunications, mobile telephony, and the Internet. Communication over transmission networks involves network effects because of the mutual benefits to subscribers of joining a network.[57] A consumer who joins the network can communicate with other subscribers. The consumer obtains benefits from communication with others, so that the consumer benefits from others' consumption of network services. If such benefits are not somehow accounted for, an externality is said to exist. There is a potential for market failure if a consumer does not recognize the benefits that her subscription to the phone network confers on others. If the consumer only recognizes her personal benefits from consumption, she may consume less of the network service than is socially optimal. Proponents of the network

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[56] For an introduction to graph theory, see J.M. Aldous & R.J. Wilson, GRAPHS AND APPLICATIONS: AN INTRODUCTORY APPROACH (New York: Springer 2000), B. Bollobás, MODERN GRAPH THEORY (New York: Springer 1998), R. Diestel, GRAPH THEORY (New York: Springer, 2d ed. 2000), W.T. Tutte, GRAPH THEORY (Cambridge: Cambridge University Press 2001), J. Gross & J. Yellen, GRAPH THEORY AND ITS APPLICATIONS (Boca Raton: CRC Press 1999), and HANDBOOK OF GRAPH THEORY (J. Gross & J. Yellen eds, Boca Raton: CRC Press 2004).

[57] See J. Rohlfs, *A Theory of Interdependent Demand for a Communications Service*, 5 BELL J. ECON. & MGMT. SCI. 16 (1974).

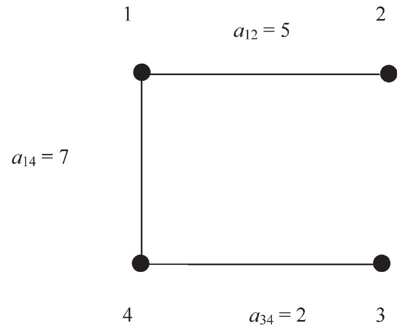

Figure 5. A network consisting of a graph $G = (\mathcal{J}, L)$ with a set of nodes $\mathcal{J} = \{1, 2, 3, 4\}$, a set of links $L = \{(1, 2)\ (3, 4), (1, 4)\}$, and numerical values assigned to the links (i, j), which are represented as a_{ij}.

effects view may recommend that the activity be subsidized to overcome the problem of underconsumption resulting from the positive externality.

In the information technology industries and selected electronics industries, there also exists the potential for network effects that are associated with interoperability. Economic actors obtain mutual benefits from exchanging information when connections between information systems facilitate communication and computation. Connected-information systems form virtual networks. The exchange of information and the processing of information that is exchanged are an important feature of the services provided by physical communications networks. The general concept of interoperability extends these properties to virtual networks. These include software–hardware interaction, software–software interaction, and hardware–hardware interaction. In electronics, for example, devices such as media players share storage media and computers and peripheral equipment have plug-and-play compatibility. Interoperability is associated with network effects because users benefit from joining the same virtual network.

The benefits of joining the same virtual network are analogous to those obtained from joining physical networks. End users derive benefits from exchanging information. When joining the same virtual network is necessary for that communication to occur, an individual who joins the network benefits from another individual joining that network. The compatibility of computers, software, and electronic devices forms the *links* of the virtual network. Individual users access the virtual network at *nodes* that consist of compatible devices.

The benefits of communication on a virtual network derive from the value of the information that is received. The same information can be shared by two or more individuals. If there is non-rivalrous consumption of information, the shared information acts as a local public good. Multiple individuals benefit from consuming the same data, music, photograph, or video.

The information that is transmitted may be a product that is consumed by each individual, such as news, financial data, or entertainment. The interoperability of virtual networks also makes possible the operation of other types of networks, particularly transport networks and transaction networks.

B. Interconnection Is Standard in the ICTE Industries

In practice, the problem of network effects is likely to be eliminated because markets provide sufficient incentives for interconnection and interoperability. When the products and services of firms in network industries are interconnected and interoperable, consumers benefit from any potential industry-wide network effects. The technology lock-in argument becomes moot because underlying network effects do not pose a problem.

Firms have a strong incentive to adapt their products to market standards to obtain a share of the market. The global market for ICTE industries is huge, with one estimate suggesting that it exceeds 6 percent of the world economy with growth rates exceeding those of the world economy.[58] This trend suggests that the world ICTE industry is approaching $3 trillion. Markets within the ICTE industries that depend on very specific technical standards are substantial. For example, the Internet employs particular protocols and represents significant data traffic and electronic commerce transactions. Local networks are a multibillion dollar industry that depends on specific IEEE standards.[59]

Forman and Goldfarb survey empirical evidence of network effects in information and communications technology industries. They point out two identification problems. Statistical correlation between user adoption decisions can be the result of relationships between the users or common unobserved factors. This means that network effects may be difficult to distinguish from lower adoption costs. Second, even if network effects could be identified, their source might not be. As they point out: "Bandwagon effects may be the result of network externalities, social network effects, or even competitive effects."[60]

For example, network effects may be present within firms due to communication between employees regarding adoption decisions in the case of video conferencing. Adoption of the technology by managers and by workers has an important effect on other employees who wish to communicate with them.[61] However, it would be incorrect to characterize decisions

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[58] These estimates are for 1997. *See* H. Miller & J. Sanders, *Scoping the Global Market: Size is Just Part of the Story*, *in ITPro* 49–55 (Mar./Apr. 1999); *see also Digital Planet: The Global Information Economy*, World Information Technology and Services Alliance, 1999.

[59] *See* J. Hurd & J. Isaak, *IT Standardization: The Billion Dollar Strategy*, 3 J. IT STANDARDS & STANDARDIZATION RES. 68 (JANUARY–JUNE 2005).

[60] Forman & Goldfarb (2006), *supra* note 7.

[61] *See* C. Tucker (2006), *supra* note 43.

within the firm as "externalities." Such adoption decisions within the firm are likely to reflect coordination rather than market failure.

Cargill and Bolin refer to standardization as a "failing paradigm." They characterize standardization as a management technique that firms employ to reduce risk, and suggest that in the information and communication technology industries, standardization "has moved from being viewed as a technical discipline to being viewed as a 'cool' marketing tool." They are concerned about "excessive proliferation" of specifications and standard-setting organizations and suggest that public policy should limit standardization.[62]

As Anton and Yao point out,

> Standards and standard-setting organizations have been an important feature of the economic landscape for many years, particularly in the information technology and communications industries.[63]

There are various explanations for the prevalence of interface standards in these industries. When firms adopt standards, the pace of adoption and overall market size are increased, according to Hurd and Isaak.[64] Given the size of the ICTE industries, the incentives for standardization are substantial. IT standardization drives increases in the size of the market, while reducing transaction costs, reducing production costs, and increasing returns on investment.[65] According to an industry survey, those firms that migrated to new standards soonest received the highest returns on investment.[66] The survey of 340 computer server and storage sites around the world found that *all* of the respondent sites used standardized servers (Intel processors and Windows or Linux operating systems).[67]

Initially, most servers were proprietary, including the IBM 3090, Digital Vax, and the Hewlett-Packard 3000. In the early 1990s, less than one-third of the servers sold was a standardized Intel system. By 2001, 88 percent were Standard Intel Architecture Servers. Most standardized servers are in the "entry level server category, those costing under $100,000."[68] Standardization of servers makes possible specialization and division of labor among different types of servers. Splitting tasks among server

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[62] C. Cargill & S. Bolin, *Standardization: A Failing Paradigm*, *in* STANDARDS AND PUBLIC POLICY 296–328 (S. Greenstein and V. Stango, eds, Cambridge: Cambridge University Press 2007).

[63] J.J. Anton & D.A. Yao, *Standard-Setting Consortia, Antitrust, and High-Technology Industries*, 64 ANTITRUST L.J. 247, 247 (1995).

[64] Hurd & Isaak, *supra* note 59.

[65] This is according to a study by J. Gantz and V. Turner (2002), "Standardization: The Secret to IT Leverage," IDC White Paper, Sponsored by Dell Computer Corp., Framingham, MA.

[66] *Id.*

[67] *Id.*

[68] *Id.*

appliances, database servers, and general purpose servers yields increased benefits from scalability, reliability, manageability, and connectivity."[69] Gantz and Turner conclude that standardization of servers "is inexorable, paralleling similar standardization adoption experiences in IT over the past 40 years."[70]

Widespread interoperability and interconnection is apparent in the ICT and electronics industries. In communications, practically everyone already is connected with everyone else. A subscriber to any communications network anywhere in the world can reach every other subscriber anywhere in the world. Practically every telecommunications network is interconnected with practically every other telecommunications network. In addition to telecommunications, the Internet is a network of networks, with nearly complete global interconnection, limited only by some authoritarian governments but not by the private sector.

Network effects cannot drive technology lock-in in the design of communications network because different types of networks are compatible. The incremental benefits of subscribing to the same network are reduced or eliminated if consumers can subscribe to different networks and still communicate with each other. All kinds of communications networks are interconnected, thus reducing or eliminating the potential benefits of having one type of network. For example, there are interconnections between traditional analog telecommunications networks, cable television-based networks, digital fiber optic, and wireless mobile networks. The benefits of network effects are achieved along with the benefits of a variety of network services and technologies. There is no need to have a single network or even a single type of network to capture network effects.

Also, network effects cannot drive technology lock-in for communications devices. Communicating networks can handle connections with very different end-user technologies. Thus, a telecommunications system can accommodate transmissions to and from traditional analog telephones, digital phones, mobile phones, fax machines, and computers. There is no possibility of technology lock-in deriving from the sacrifice of product variety to obtain network effects.

The joint benefits of subscribing to the same network are reduced further because consumers often subscribe to multiple networks so that not all consumers need be on the same network for communications to take place. Consumers often belong to multiple communications networks including traditional telecommunications, mobile telephony, the Internet, and Wi-Fi systems. Consumers often have access to different communications networks at home and at work. The question of access to communications networks is essentially moot in developed economies where access to telephony is

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[69] *Id.*

[70] The information in this paragraph is drawn from Gantz & Turner (2002), *supra* note 65.

practically universal and Internet access is nearly so.[71] In addition, the Telecommunications Act of 1996 expands the regulatory concept of universal service to one that expands with the development of new technologies.[72]

Network effects are unlikely to drive technology lock-in in software used for Internet communications. Multiple browsers are available at no cost and can be readily downloaded from the Internet. Consumers often have more than one browser. Providers of browsers have an incentive to allow users to reach as many web pages as possible. A similar situation exists with search engines. Consumers can access multiple search engines online and can switch easily between them. Providers of search engines seek to maximize the benefits of users, which means that such engines will not exclude either users who wish to search the web, nor will they exclude web pages that users wish to find.

Various market forces handle the network effects associated with multiple media player formats. Computer media player software exists in multiple formats including Microsoft Media Player, Adobe Flash Player, and RealPlayer. Network effects create the potential for a virtual network of players and media in different formats. However, the players are available for free, easily downloaded from the Internet, and not mutually exclusive because a computer user can install the software for multiple players on a single computer. Thus, any computer user can employ whatever media player is needed to read a particular file. In addition, the same information can be made available in multiple formats. As a consequence, most computer users can choose between formats for many types of information.

Even if a company offers a proprietary format for a media player, there are competing alternatives. For example, Apple iTunes Store offered a vast library of songs and other content subject to a proprietary format. The Apple iTunes could only be played on the Apply iPod portable device and were subject to "digital rights management" (DRM) copying restrictions. A competitor, eMusic, offered downloads of songs without restrictions for customers who paid subscription fees. Competitive alternatives expanded significantly when Internet retailer Amazon.com offered songs from many music companies that were free of DRM restrictions in the MP3 format that is used in practically any media player. Suppliers of recordings to Amazon include 20,000 independent recording labels and major labels such as EMI and Universal Music Group.[73] At least initially, Amazon's restriction-free songs were offered at a lower price than the restricted offerings of i-Tunes.

Platforms exist in electronic commerce, in the form of technical standards for the electronic exchange of data between companies. Innovations in

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[71] See D.F. Spulber & C.S. Yoo (2008) for additional discussion of access.

[72] On regulation of broadband, see R.W. Crandall & J.G. Sidak, *Competition and Regulatory Policies for Interactive Broadband Networks*, 68 S. CAL. L. REV. 1203 (1995).

[73] See Jonathan Richards, *Amazon Launches Music Download Service to Challenge iTunes*, TIMES ONLINE, September 26, 2007.

communications and computation as applied to business documents avoid the need to translate computer files into paper documents, thereby increasing the speed and accuracy of transactions. There is a wide-ranging set of standards for electronic data interchange (EDI) on private networks that predates the Internet. Extensible markup language (XML) provides standards for documents and data transmission over the Internet developed by the World Wide Web Consortium. The advantage of document standardization is ease of communication and computation in retail, wholesale, and general inter-business transactions.

Collections of technical standards exist in many industries where independent producers supply substitute products that are interchangeable and complementary products that work together. Thus, cameras and film share technological standards that allow the products to be used together, and there are multiple providers of cameras and of film that follow the technical standards. These standards exist in many high-tech industries such as audio systems, video systems, and mobile phones. Platforms exist in many other types of industries in which compatible components are needed, including automobiles, aircraft, and industrial machinery.

There are over 100 national and international standard-setting bodies in the ICTE industries. Among the major international standard-setting organizations are the International Organization for Standardization (ISO), the International Telecommunications Union (ITU), ECMA International, the Institute of Electrical and Electronics Engineers (IEEE), the Internet Engineering Task Force (IETF), the World Wide Web Consortium (W3C), the International Electrotechnical Commission (IEC), and the Internet Society (ISOC). International organizations also coordinate with each other through such mechanisms as the ISO/IEC/Joint Technical Committee 1 (JCT1), and through overlapping memberships. Standard-setting organizations develop and promulgate a wide range of technology specifications and product standards. For example, ECMA International deals with ICT and consumer electronics (CE) standards. These include standards for: scripting and programming languages; communications technologies; product safety; environmental design considerations; acoustics and electromagnetic compatibility (EMC); optical storage; volume and file structure; universal 3D open file format; holographic information storage systems (HISS); Office Open XML formats; and XML paper specification (XPS).[74]

V. MARKETS PROVIDE INCENTIVES FOR COORDINATION AND INTEROPERABILITY

Firms that provide innovations have economic incentives to coordinate product standards with each other. These standards should address potential

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[74] This list is from www.ecma-international.org.

network effects and thus eliminate the possibility of technology lock-in. Network effects, where they exist, increase the incentives for standardization and interoperability. This suggests that network effects should not be identified as causing technology lock-in but rather they may enhance the diffusion rates of new technologies.

Consumer coordination in the small and in the large addresses the problem of social benefits potentially posed by network effects. Moreover, the possibility of network effects largely is confined to the ICT and electronics industries. Even if network effects are present, market institutions capture many of the potential benefits, eliminating the possibility that network effects can cause technology lock-in.

A. Firms Have Incentives to Provide Interoperability

Potential externalities due to network effects that potentially underlie technology lock-in are eliminated if firms offer compatible products. Consumers obtain all of the mutual benefits of consumption when physical and virtual networks are interconnected. The question is whether firms have incentives to interconnect when it is efficient to do so. Katz and Shapiro show that firms need not engage in interconnection even when doing so is socially optimal. Their result is predicated on quantity competition between firms. However, their results can be reversed when firms engage in price competition. Then, under some conditions, profit-maximizing firms choose to interconnect if it is socially efficient to do so. Firms may even choose to interconnect when it is socially inefficient. Forcing firms to interconnect through antitrust and government regulation may make consumers worse off than they would be otherwise.

Firms' decisions to engage in costly interconnection depend on the nature of competition. When firms employ quantity instruments such as capacity setting, they are said to compete using "strategic substitutes." When firms employ price instruments, they are said to compete using "strategic complements."[75] The technology lock-in results obtained with strategic substitutes can be reversed when firms compete with strategic complements. Price competition tends to be a more accurate description of competition than quantity competition.[76] In practice, firms generally compete through price adjustment. Other competitive instruments, such as product features, innovation, marketing, sales, and service, accompany price competition.

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[75] *See* J. Bulow, J. Geanokoplos & P. Klemperer, *Multiproduct Oligropoly: Strategic Substitutes and Complements*, 93 J. POL. ECON. 488 (1985). The actions of two firms are strategic substitutes (complements) if an increase in one firm's action lowers (raises) the marginal effects on its profits of the other firm's action.

[76] This was the substance of Bertrand's 1883 critique of the 1838 Cournot model. This debate lies at the foundation of much of the economic field of Industrial Organization. *See* D.F. Spulber, REGULATION AND MARKETS ch. 17 (Cambridge, MA: MIT Press 1989).

Consider how competitive firms decide whether or not to make their technology compatible. Total welfare generally is composed of firms' profit and consumers' surplus. If firms decide to make their products compatible, the welfare effects are composed of the changes in profits (Π) and consumers' surplus (CS).

$$\Delta W = \Delta\Pi + \Delta CS$$

Making products compatible is costly. Accordingly, it is efficient to make products compatible when the welfare benefits exceed the cost of compatibility. If the cost of compatibility is F, then compatibility is desirable if and only if

$$\Delta W \geq F$$

Firms will choose to make their products compatible if and only if

$$\Delta\Pi \geq F$$

If profits increase with compatibility, this will motivate firms to provide compatibility. The critical issue is whether compatibility increases consumers' surplus. If compatibility increases consumers' surplus, then compatibility increases social welfare more than firms' profits, so that firms are less motivated to choose compatibility than is socially optimal. Conversely, if compatibility decreases consumers' surplus, then firms are more motivated to choose compatibility than is socially optimal.

Katz and Shapiro show that when firms compete through quantities, compatibility always increases consumers' surplus.[77] This implies that firms do not supply enough compatibility because there are situations in which doing so is not profitable even though it is socially optimal. Their result depends on the fact that compatibility not only yields network effects but also increases the effects of competition, increasing total industry output and reducing the price paid by consumers. The public policy implications of this result, as emphasized by Katz and Shapiro, are for government to favor compatibility through industry coordination and other means.

Consider now the implications of price competition. To illustrate the effects of price competition, consider the classic model of differentiated products competition in a duopoly.[78] There is a continuum of N consumers represented by the interval of addresses from 0 to N. This also represents the space of possible products, with firm A located at zero and firm B

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[77] Katz & Shapiro (1985).

[78] This is the standard Hotelling model of a differentiated duopoly.

located at N. The number of consumers who buy technology A is n and the number of consumers who buy technology B is the remainder, $N - n$.

Suppose that there are common network effects as well as idiosyncratic preference effects. If the two products are not compatible, network benefits are $g(n)$ for technology A and $g(N - n)$ for technology B. If the two products are compatible, then network benefits are $g(N)$ for both technologies. The idiosyncratic benefit effect of the marginal consumer is $h(n)$ for technology A and $h(N - n)$ for technology B. The firms offer prices p^A and p^B respectively and choose prices to maximize profits.[79]

Network effects only play a demand-side role when products are not compatible. Thus, the price elasticity of demand only depends on network effects when products are not compatible.[80] This means that demand will be more elastic without compatible products and less elastic with compatibility. As a result, the firms will choose higher prices at equilibrium with compatibility.[81]

Compatibility thus raises prices when firms engage in price competition. The price increase due to compatibility offsets the gain in consumers' surplus that is due to the network effects of compatibility. This means that compatibility can increase or decrease consumers' surplus depending on whether the network effects of compatibility are greater or less than the price effects of compatibility.[82] When the price effects of compatibility outweigh the benefits, consumers' surplus falls. Then, the profitability of making products compatible outweighs the social welfare effects. Firms will choose compatibility whenever it is socially efficient to do so. Firms also will

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[79] Profits are respectively, $\Pi^A = p^A n$ and $\Pi^B = p^B(N - n)$. The marginal consumer is indifferent between the two technologies. Without compatibility, the marginal consumer is determined by $g(n) - h(n) - p^A = g(N - n) - h(N - n) - p^B$. With compatibility, the marginal consumer is determined by $g(N) - h(n) - p^A = g(N) - h(N - n) - p^B$.

[80] Demand elasticity for product A without compatibility equals

$$\eta^A = -\frac{\partial n}{\partial p^A}\frac{p^A}{n} = \frac{-1}{(g'(n) - h'(n)) + (g'(N - n) - h'(N - n))}\frac{p^A}{n}.$$

Demand elasticity for product A with compatibility equals

$$\eta^A = \frac{\partial n}{\partial p^A}\frac{p^A}{n} = \frac{-1}{-h'(n) - h'(N - n)}\frac{p^A}{n}.$$

[81] The equilibrium when marginal costs are zero equates marginal revenue to zero, so that $p(1 - 1/\eta) = 0$. The equilibrium prices are chosen so that for each firm, elasticity of demand equals one. Without compatibility, firm A's price equals $p^A = Nh'(N/2) - Ng'(N/2)$. With compatibility, firm A's price equals $p^A = Nh'(N/2)$ so that the price effect is $\Delta p^A = Ng'(N/2)$. At the equilibrium in either case, the two firms split the market at $N/2$. Compatibility increases prices and the firms' profits. The analysis generalizes to positive marginal costs.

[82] The formal representation of these two effects is as follows: $\Delta CS = g(N) - g(N/2) - Ng'(N/2)$. If $g(n) = \sqrt{n}$, for example, $\Delta CS = \sqrt{N}\,(1 - \sqrt{2}\,)$, which is less than zero.

choose compatibility in some situations when it is not socially efficient because they obtain greater private benefits from compatibility.

Farrell and Saloner, in their 1992 article on technological compatibility, present a Hotelling-type model with product variety. In their setting, the customers of the two firms decide whether or not to purchase converters. They observe that consumer decisions about purchasing converters illustrate the "irresponsibility of competition" because it may lead to less standardization and compatibility. They also find that both firms favor efficient converters due to the pricing game. Assuming that one technology is "dominant," they point out that a consumer that buys the dominant technology confers a greater network externality on others than a consumer who buys the minority technology and a converter. They conclude that "social welfare may be higher if converters are not available."[83]

In a setting without network externalities, Matutes and Regibeau find that firms will choose to make their products compatible to reduce the effects of price competition.[84] Economides shows, also in a model without network externalities, that firms in oligopolistic competition will choose compatibility.[85]

Antitrust policy makers should not assume that markets supply insufficient product compatibility. My analysis shows that when firms compete on price, as is almost always the case in practice, firms benefit from compatibility and these benefits can outweigh the costs of providing compatibility. Firms' net benefits of providing compatibility can be greater than social benefits so that firms provide compatibility at least when it is socially efficient to do so. Antitrust efforts to promote compatibility when firms do not choose to do so can be socially inefficient and can result in reductions in consumers' surplus. Antitrust efforts to promote compatibility need not be in consumers' best interests.

B. Benefits from Product Differentiation Can Overshadow Network Effects

The assumption that network effects are "strong" clearly is an even stronger assumption than simply assuming that network effects exist. The "strong" network effects requirement means that it is better to have a single network than a variety of networks. However, this powerful assumption denies the benefits to consumers of product variety.

Consumers also benefit from consuming diverse products when there are different underlying technologies. Generally, different technological solutions

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[83] Farrell & Saloner (1992), *supra* note 7, at 32.

[84] C. Matutes & P. Regibeau, *"Mix and Match": Product Compatibility Without Network Externalities*, 19 RAND J. ECON. 221.

[85] N. Economides, *Desirability of Compatibility in the Absence of Network Externalities*, 79 AM. ECON. REV. 1165 (December 1989).

offer tradeoffs. For different purposes, a glass jar, or a plastic container, or a metal can be the best container. Each container has advantages and disadvantages. Similarly, there are diverse technologies underlying product diversity in computer software, pharmaceuticals, medical devices, lasers, engines, textiles, and so on. Public policies that require standardization would eliminate the benefits of multiple technologies.

Technological progress is by no means confined to the ICTE industries. Innovation occurs in practically every industry. Innovations involve new production processes, new products, and new transaction methods in almost any sector of the economy. Advances in materials sciences, mechanical engineering, biology, chemistry, physics, optics, electronics, and aerospace translate into a broad range of process and product innovations. The claim that technology standards and compatibility generate network effects does not apply to almost any good. Examples of standardization occur almost everywhere including nuts and bolts, hot dogs and buns, engines and sparkplugs, and anything covered by the National Bureau of Standards.[86] The problems attributed to network effects are likely to be confined to the ICTE industries. Therefore, discussions of technology lock-in should not continue to make general claims that extend across the economy.

The benefits of product differentiation can overcome potential benefits from joining the same virtual network. In this case, the network effects externality does not occur because it is efficient for consumers to choose a variety of products. As a result, technology lock-in cannot occur because it is efficient for there to be multiple technologies in the marketplace.

Technology lock-in is an issue only if adoption of one technology somehow prevents the adoption of another better technology. However, for most technologies there are substitutes that deliver different features. The technologies are embodied in consumer products that are horizontally differentiated. Consumers have heterogeneous preferences and may prefer different combinations of product features.

Thus, some consumers may prefer an IBM-compatible personal computer (PC) whereas others prefer an Apple computer. There may be many types of software applications that solve the same problem. Substitute goods may employ different technologies, so that, for example, a voice mail, an e-mail, a text message, or an instant message all provide substitute messages. Individual consumers may differ in their preference rankings of products based on these technologies. It can be efficient for there to be multiple substitute products. Correspondingly, it can be efficient for economies to adopt multiple substitute technologies.

Moreover, a mixture of technologies can be better than a single technology. For example, a consumer is often better off with a combination of communications technologies. Many consumers subscribe to multiple

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[86] *See*, *e.g.*, Farrell & Saloner (1985).

communications networks even if two technologies are vertically differentiated in terms of quality; this does not imply that there should be only one technology adopted. Technologies can have different costs. Consumers have different preferences over price, quality, and combinations so that multiple technologies are desirable. When having multiple technologies is efficient, the technology lock-in story breaks down. It can be desirable to adopt more than one technology. The notion that being stuck on the wrong one prevents a switch to the best one no longer applies.

C. Economies of Scale and Increasing Returns to Innovation Do Not Create Technology Lock-in

Economies of scale and the related concept of increasing returns to innovation do not create technology lock-in. Benefits that firms derive from the standardization of inputs to production do not create network externalities because firms coordinate with their suppliers to address any potential network effects.

Some sources of network effects, and hence technology lock-in, are attributed to the demand side of input markets. Firms benefit from purchasing standardized inputs, including parts and components. The use of interchangeable parts facilitates mass production and generates economies of scale.[87] The argument is that firms that purchase interchangeable parts from suppliers experience network effects on the demand side of the market for parts. If more firms adopt a particular technological standard in their production processes, they will benefit from joining a broader demand for a particular type of part. The greater the demand by auto makers for a particular type of sparkplug, the better or the cheaper will be the sparkplug. Then auto makers can employ the standard sparkplug in assembling automobiles.

The economies-of-scale argument is another form of indirect network effect. As Liebowitz and Margolis observe, these indirect effects are mediated by markets.[88] Firms' transactions with suppliers internalize the benefits and costs of parts. These are nothing more than standard market transactions without external effects. If firms benefit from using standardized parts, suppliers will provide them with standardized parts. Firms also can choose to coordinate their adoption of technological standards as it affects their demand for parts by tacit coordination, by merger, by the formation of trade associations, or by participation in standard-setting organizations.

The same objection applies to a related argument based on "increasing returns" that occur over time. Arthur, for example, suggests that adoption of a technology leads to experience and improvements in the

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[87] *See*, *e.g.*, Farrell & Saloner (1986).

[88] Liebowitz & Margolis (1994) at page 139 conclude that indirect network externalities "describe nothing more than welfare-neutral interactions that occur in properly functioning markets."

technology.[89] Nate Rosenberg refers to this effect as "learning by using."[90] This effect is necessarily dynamic because it refers to a time-consuming process of technological improvements. The technology in question is not embodied in a specific product but rather in a series of different products developed and introduced over time.

The dynamic increasing returns type of network effect requires inventive activity by firms. Arthur illustrates the concept of increasing returns by noting the "constant modification" and significant improvements in the structure, wings, capacity, and engines of the Boeing 727. Clearly, these types of improvements result from the R&D of Boeing and its suppliers. This should not be classified as a demand-side effect because it is clearly on the production side.

The fact that improvements in technology are made by a firm suggests that the firm owns that technology. Alternatively, there may be many firms that create improvements in a technology – but that possibility suggests that the next generation of products might be better characterized as multiple technologies offered by different firms. In this way, "learning by using" seems incompatible with the assumption that the technology is unsponsored. If the technology is not sponsored and is being improved by many firms, the technology must have some sort of "open source" arrangement with a consortium of firms making improvements on a commonly available product. Accordingly, the concept of increasing returns explicitly requires ownership of the technology by firms or cooperation by firms to improve the technology.

When the benefits of a common technology are due to economies of scale in manufacturing, such cost savings are the same as any other type of economies of scale. Well-known sources of economies of scale include specialization and division of labor, amortization of fixed costs, automation and mechanization of production, and volume–surface relationships. These types of scale effects exist in practically any industry and usually require standardization of products. When economies of scale are significant, firms will expand production through growth or mergers and acquisitions. Competition between firms will drive industries toward larger-scale production. All other things equal, such competition is sufficient to guarantee that products are standardized for efficient large-scale production.

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[89] *See* Arthur (1989); *see also* R.R. Nelson & S.G. Winter, AN EVOLUTION THEORY OF ECONOMIC CHANGE (Cambridge, MA: Belknap-Harvard University Press 1989); A.B. Atkinson & J.E. Stiglitz, *A New View of Technological Change*, 79 ECON. J. 573 (September 1969); K.J. Arrow, *The Economic Implications of Learning by Doing*, 29 REV. ECON. STUD. 155 (June 1962).

[90] N. Rosenberg, INSIDE THE BLACK BOX: TECHNOLOGY AND ECONOMICS (Cambridge: Cambridge University Press 1982).

D. Switching Costs Do Not Create Lock-in

Another view of technology lock-in is based on consumer switching costs.[91] David, for example, restates the network externality argument in the context of the typewriter keyboard but adds that "[t]he occurrence of this 'lock in' as early as the mid-1890's does appear to have owed something also to the high costs of software 'conversion' and the resulting *quasi-irreversibility of investments* in specific touch typing skills."[92] The argument is that, because it is costly for consumers to adopt a new technology, they may get stuck with an old and inferior technology, hence lock-in occurs.

The antitrust policy implications of switching costs are based on an analysis of competition. The presence of switching costs mitigates the effects of price competition. Initially, firms compete aggressively to attract customers. Once they have an installed base, the firms can raise prices and extract monopoly rents because it is costly for customers to switch to competing products. The competitive frictions created by switching costs are similar to those due to product differentiation, which confers some market power. There is no basis for government intervention in the market based on brand identification or attractive product features. There should be no basis for government intervention based on competition with switching costs.[93]

The argument that technology lock-in is based on past adoption costs is fundamentally flawed. David's point about the "quasi-irreversibility of investments" in learning about the old technology is simply the fallacy of sunk costs. Because learning costs are sunk, the consumer's past investments are irrelevant to the adoption decision. The only costs that matter are those related to the future adoption of a competing technology. The consumer's decision depends on the relative benefits of the two technologies in comparison with the costs of adopting the new technology.

The consumer costs of adopting a new technology certainly offset the benefits of the new technology. However, it is incorrect to interpret this as market failure. Purchasing almost any product involves some transaction costs. Changing to a new product or technology generally involves some related learning and costs of adjustment. Consider the learning costs involved in visiting a new restaurant, traveling to a new city, or buying a new car. The transaction costs and switching costs are just part of the total purchase costs. It is efficient for the consumer to take these costs into account in evaluating the net benefit of a new product. If switching costs raise the hurdle, the decision is still efficient.

Switching costs based on transaction costs, adjustment costs, or learning costs are ubiquitous. They are not confined to innovative products.

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[91] For an overview of the literature, see J. Farrell & P. Klemperer (2006), *supra* note 31.

[92] David (1985), *supra* note 2, at 335–36.

[93] In fact, switching costs can reduce the profits of incumbents. *See* G. Biglaiser, J. Crémer, & G. Dobos, *The Value of Switching Costs* (University of North Carolina, Working Paper, 2007).

These costs are simply normal economic frictions. Market institutions exist to address these costs. Companies expend resources on marketing and sales efforts to mitigate such costs. They offer price discounts to new customers to offset the costs of switching. Intermediary firms such as retailers help to reduce transaction costs. There is no basis for public policy intervention to mitigate transaction costs.

It is important to distinguish the choice between two new technologies and the decision to switch from an old technology to a new technology. Switching costs certainly do not create bias in how consumers choose between two new technologies. Consumers choose between the net benefits of the new technologies. They should evaluate all of the features of the new technologies. The costs of learning and adapting to a new technology are certainly among its features and should be taken into account. If it is easier to learn to use one of two otherwise similar technologies, it is efficient to choose the one with the lower learning costs.

The economic literature generally assumes that individual consumers have heterogeneous switching costs. For example, one consumer may have higher costs of learning about a new technology than another consumer. Accordingly, some consumers find it easier to switch to new technology. Some consumers enjoy trying new products and sometimes become "early adopters." Not all consumers will switch when a new product comes along. The result is beneficial product variety, not market failure. Continual adoption of new products and technologies throughout the economy strongly suggests that, if there are frictions associated with switching costs, they are an integral part of technological change.

E. Evidence Suggests Technological Change Rather Than Technology Lock-in

The persistence and acceleration of technological change throughout the economy strongly suggest that technology lock-in is imaginary. The rapid pace of technological advances in the ICT industries and electronics in comparison with other industries should be sufficient to reject the notion that technology is locked in by network effects. The extremely fast adoption of new products in the ICT and electronics industries indicates the ease of consumer adoption and the ability of markets to coordinate decisions. Such new products include laptop computers, DVDs, the iPod, and the iPhone. Clearly, developed economies lack systematic network effects.

The evidence for technology lock-in is both anecdotal and highly questionable.[94] Liebowitz and Margolis present a critical evaluation of path

[94] The main example given to show that markets fail due to technology lock-in is that of the design of the typewriter keyboard. The story of the keyboard is inaccurate as shown by Liebowitz & Margolis (1990). As other evidence that markets tend to choose the wrong

dependence.[95] There is scant evidence that governments are better than consumers and firms at making decisions about technology adoption.

The process of adoption of an innovation over time is referred to as diffusion. The diffusion of innovation has been widely studied in many disciplines.[96] Entrepreneurs and established firms create innovations by commercializing inventions. After the innovation is introduced to the market, the process of diffusion begins. Sequential adoption decisions by consumers lead to dynamic patterns of total sales.

The presence of lags in the diffusion of technological advances need not indicate problems in the process of adoption. Diffusion rates depend on the costs of adopting the new technology and the costs of learning about the benefits of the new technology. Thus, adoption lags can be efficient responses to adjustment costs, learning time, and the resolution of uncertainty.[97]

Saloner and Shepard argue that network effects affect diffusion rates for innovation. They find that banks with more branches adopted automated teller machines (ATMs) more rapidly than smaller banks, even when adjusting for the size of the firm.[98] However, such a result does not indicate market failure due to network externalities. Rather, the adoption of ATMs depends on business decisions by a profit-maximizing firm. Banks with greater emphasis on retail consumers will have more branches and are likely to emphasize additional services such as the provision of access to ATMS.

Perceived “lags” in diffusion can be a matter of interpretation of the data. Building sales requires time-consuming communication with consumers through media, marketing, and sales. It also takes time for consumers to learn about the innovation, to decide whether or not to adopt it by

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technology and then get locked in, economists usually point to the success of VHS over Beta in the market for video cassette recorders. Supposedly, the market standard VHS was inferior to the failed Beta technology but VHS was more established. However, there is substantial evidence that this example of technology lock-in is also historically and technically inaccurate. *See* Liebowitz & Margolis (1999). Another questionable example of path dependence concerns the inefficiency of small rail cars used to carry coal in Great Britain. Va Nee L. Van Vleck shows that the coal cars were part of a larger system that included local delivery by horse cart and later by truck. Large rail cars would have been likely to raise total costs of delivery and so were efficient as part of a transportation system. *See* V.N.L. Van Vleck, *Delivering Coal by Road and by Rail in Great Britain: The Efficiency of the “Silly Little Bobtailed Wagons”*, 57 J. ECON. HIST. 139 (1997).

[95] *See* Liebowitz & Margolis (1994) & (1995).

[96] *See* B.H. Hall, *Innovation and Diffusion*, *in* THE OXFORD HANDBOOK OF INNOVATION ch. 17, 459–84 (J. Fagerberg, D.C. Mowery, & R.R. Nelson, eds, Oxford: Oxford University Press 2005). For a sociological overview, see E.M. Rogers, DIFFUSION OF INNOVATIONS (New York: Free Press, 4th ed. 1995).

[97] Hall (2005), *supra* note 96.

[98] G. Saloner & A. Shepard, *Adoption of Technologies With Network Effects: An Empirical Examination of the Adoption of Automated Teller Machines*, 26 RAND J. ECON. 479 (1995).

purchasing the product, to search across suppliers for the product, and to negotiate the purchase of the product. The time involved in communication, learning, search, and purchasing generates lags in sales. In addition, consumers may not have an immediate need for the product but may develop needs over time as their personal circumstances change. Consumers may delay their purchase of the product until they need to replace an existing product. Consumers may delay their purchase until they observe the consumption of others as a means of gathering information. Thus, imperfect information and transaction costs can help to explain the rate of diffusion.

Changes in economic variables, such as incomes and the availability and prices of substitute goods, are likely to affect diffusion rates. Finally, demographic factors that can affect diffusion rates include the rate of population growth and the age distribution of the population. The standard diffusion model can be generalized to include price effects among other market data.[99] The presence of network effects need not change the basic model of diffusion.[100]

Innovation rates are affected by changes in marketing expenditures, sales efforts, and product prices.[101] Diffusion rates also are explained by improvements in product quality, which boosts sales of the innovation. If the quality of innovation improves over time, the rate of adoption will increase as well. Increased benefits yield greater adoption levels and thus do not imply problems of diffusion. As an innovation diffuses, the number of adoptions provides innovators with information that indicates the market value of the innovation. The success of an innovation can signal the demand for improvements in product quality.

The path-dependence view argues that increased sales stimulate innovation, which creates network effects between past and future adopters.

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[99] See particularly F. Bass, *The Relationship Between Diffusion Rates, Experience Curves, and Demand Elasticities for Consumer Durable Technological Innovation*, 53 J. BUS. 551 (July 1980); see also S. Kalish, *Monopolistic Pricing with Dynamic Demand and Production Costs*, 2 MARKETING SCI. 135 (Spring 1983).

[100] The network effects model can also be included in the diffusion equation. Let $n^*(p)$ be the equilibrium adoption level generated by the network effects model, see Figure 1. Let a and b be fixed parameters and let $n(t)$ be cumulative sales at time t. Then, the diffusion rate can be written as:

$$\frac{\mathrm{d}n(t)}{\mathrm{d}t} = (a + bn(t))(n^*(p) - n(t))$$

Let $n(0) = n_0$ be given. The dependence of the rate of adjustment on cumulative sales reflects the effects of sales on information received by prospective consumers. The diffusion rate yields a logistic curve, which relates cumulative sales to time.

[101] For an overview of diffusion models in marketing, see Chapter 10 in G.L. Lilien, P. Kotler, & K.S. Moorthy, MARKETING MODELS (Englewood Cliffs, NJ: Prentice-Hall 1992). See the review of work on advertising, prices, and sales effort on page 473. The standard model of the diffusion of an innovation is due to F. Bass, *A New Product Growth Model for Consumer Durables*, 15 MGMT. SCI. 215 (January 1969).

However, the decisions about product improvements are internalized by the decisions of the innovating firms. This interpretation of diffusion requires treating a series of improved products as if they represent a single innovation, although technically they comprise a series of innovations.[102]

VI. ANTITRUST IMPLICATIONS OF TECHNOLOGY LOCK-IN

Advocates of technology lock-in suggest that it provides an instrument of monopolization because network effects attract consumers to one technology standard. For similar reasons, it is argued that technology lock-in is an instrument of exclusion because consumers will not switch to products offered by entrants due to excess inertia. In addition, technology lock-in is said to provide incentives for monopolization and exclusion because firms will seek to be the technology winner.

The technology lock-in and network effects concepts are highly influential in antitrust policy making. For example, the European Commission's Microsoft decision mentions lock-in six times and network effects 34 times. In servers, the Commission argued that Microsoft should supply software interoperability information to its competitors because "[t]echnologies that will lead to a further lock-in into Microsoft's products at the work group server and client PC level are quickly gaining traction in the market."[103] With regards to media players, the Commission stated that "[t]he network effects characterizing the media software market . . . translate into entry barriers for new entrants."[104]

A. Technology Lock-in and Monopolization

The technology lock-in literature suggests that network effects change the connection between competition and information disclosure. According to this view, because consumer expectations drive the outcome, firms will mislead consumers. If consumers cannot coordinate effectively, imperfect expectations will lead to inefficient technology adoption decisions. If the lower-quality innovation is expected to win, it will—leading to an inefficient outcome.[105] The heart of the argument is that firms will seek to manage consumer expectations so as to obtain a monopoly.

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[102] This might apply to the often-cited example of improvements in Boeing aircraft. *See* Hall (2005), *supra* note 96, at 470; N. Rosenberg, *Factors Affecting the Diffusion of Technology*, 10 EXPLORATIONS IN ECON. HIST. 3 (1972); N. Rosenberg, *Learning by Using*, *in* N. Rosenberg, INSIDE THE BLACK BOX 120–40 (Cambridge: Cambridge University Press 1982).

[103] Commission Decision, *supra* note 1, at 207.

[104] Commission Decision, *supra* note 1, at 115.

[105] *See* S.M. Besen & J. Farrell, *Choosing How to Compete: Strategies and Tactics in Standardization*, 8 J. ECON. PERSP. 117 (1994), and the references therein.

Firms compete not only through prices, product quality, and innovation. They also compete in the supply of information. Firms normally engage in advertising and sales efforts to attract customers. Such competition tends to increase the amount of information that is made available to consumers. Competitors will point out inaccuracies in each others' marketing campaigns. When competitors disclose different information about product features, consumers will seek additional disclosures to aid in comparison shopping. The intensity of competition is likely to lead to greater amounts of information for consumers.

How one interprets the management of expectations is critical. One interpretation of the management of expectations is positive. Firms will provide information to consumers that helps consumers to coordinate their technology adoption decisions. The result is "spontaneous order." The market thus captures the benefits of network effects. Consumers, without being coerced, use the signals provided by firms to choose the best technology and the market functions efficiently. The result is intermediation of network effects and well-informed technology adoption decisions.

The other interpretation of management of expectations is a negative one. Besen and Farrell conclude that

> because the prize is so tempting, sponsors may compete fiercely to have their technologies become the standard, and this competition will generally dissipate part—perhaps a large part—of the potential gains.[106]

The question is whether market incentives for intense competition enhance economic efficiency or somehow contribute to anticompetitive behavior.

The "tempting prize" argument is not sufficient to establish incentives for monopolization and exclusion. Monopoly profits could be earned in any industry, whether or not network effects are present. There is no evidence to suggest that potential profits in network industries are any greater than in any other industry. Network industries provide profits that are neither more nor less tempting than in other industries. Competition exists throughout the economy and should have the effect of equalizing rates of return across industries. There are many factors that affect profitability and opportunities for entry. It is highly unlikely that network industries are systematically more tempting than other industries.

The "tempting prize" argument suggests that exclusion yields greater returns in an industry in which technology standards matter. Technological change occurs throughout the economy, it is not confined to any specific industry. Scientific progress in computers, software, biotechnology, chemistry, physics, electronics, materials sciences, and other areas affects multiple industries. Technology standards play an important role wherever

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[106] *Id.* at 119.

technological change occurs because there are often many ways to configure products and production processes. There is not reason to suppose *a priori* that standards matter more in particular sectors of the economy.

Besen and Farrell apply the "tempting prize argument" to characterize potential competitive strategies of firms that have consequences of monopolization and exclusion. They identify four strategies. Competing firms whose products have incompatible technologies may offer low "penetration" prices to build market share, try to attract the suppliers of complements, preannounce new products, and offer guarantees of low prices in the future.[107]

These four strategies do not provide a useful guide for antitrust policy because they are difficult or impossible to distinguish from normal forms of vigorous competition in any industry. They certainly do not appear unique to network industries.

Firms generally offer discounts to introduce new products, helping consumers to learn about new product features or building new brands. Firms generally enjoy benefits from producers of complementary products. Firms often announce new products, whether to attract the attention of potential customers, to raise money from investors, or to signal to competitors. Vaporware is not confined to computer hardware and software. Firms often enter into contracts with customers that involve guarantees of future prices. These activities are not directly related to technology standards.

Why do some firms, and the technology that their products embody, succeed whereas others fail? There are many explanations. The most appealing possibility is that the market test is effective. Better products win because many consumers, firms, and market intermediaries evaluate the technology. The winning technology reflects the combination of information gathering and decisions by a large number of economic agents. As with the efficient market hypothesis in financial markets, the prices of technology products embody all of the information available to market participants. Refuting the efficient market hypothesis for technology products would require a demonstration that the information available to market participants can be concealed or distorted or that markets cannot make effective use of the information.

Additional factors affect market outcomes in markets for technology without necessarily suggesting inefficiency. Firms offering the technology may be highly innovative and well managed. The firm may be located in a country that has a comparative advantage in developing the technology or in producing the good that employs the technology. The efficiency of the outcome depends on the benefits received by the final consumer.

For example, the success of the Japanese consumer electronics industry in the decade 1975 to 1985 depended on technologies developed by the Sony

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[107] *Id.* at 122–24.

Corporation.[108] Also, Japanese companies supplied Europe with computer systems and provided the U.S. with memory chips.[109] At the same time, Europe's computer and consumer electronics industries declined significantly, as did the U.S. consumer electronics industry.[110] However, Japanese firms were not competitive internationally in chemicals and pharmaceuticals.[111] Also, U.S. firms were highly successful in the production of microprocessors, particularly Intel, Motorola, and Texas Instruments.

These systematic geographic aspects of technological innovation and diffusion transcend notions of network effects and imperfect competition. First movers were not successful in either consumer electronics or in computers. For example, U.S. companies such as RCA, Philco, CBS, and Zenith were displaced by Japanese companies, particularly Sony and Matsushita. Among the underlying geographic aspects of comparative advantage are differences in scientific invention, product development capabilities, and management skills. The specialization observed in different countries does not necessarily reflect absolute advantages in skills but instead depend on the returns to specialization in particular activities including invention, commercial development, and manufacturing. In addition, relative wages combined with relative technological efficiency determine specialization and the direction of international trade.

B. Technology Lock-in and Exclusion

Technology lock-in also can lead to misguided antitrust policy towards exclusion. The policy prescription begins with the assumption that a given firm holds a dominant market position due to technology lock-in. Because network effects underpin the technology lock-in model, this effectively assumes that the firm's dominant position is due to network effects. The next step is to characterize the dominant firm's exclusionary behavior based on the network effects model.

If the dominant firm does not license that technology or otherwise make its technology available to its competitors, then that firm is alleged to exclude others from the market. In this context, establishing exclusionary behavior does not require either an intent to exclude or actions to exclude. There is no need for a smoking gun. Rather, antitrust authorities merely would have to show that a firm does not make its technology available to others for purposes of interconnection or interoperability.

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[108] *See* A.D. Chandler, INVENTING THE ELECTRONIC CENTURY 2 (New York: Free Press 2001).

[109] *Id.*

[110] *Id.* Chandler highlights the importance of various firm capabilities in R&D, marketing, production, and management.

[111] *Id.* at 238.

The antitrust authorities first need to establish the preconditions for technology lock-in, namely the potential presence of network effects. It is perhaps not surprising that antitrust authorities tend to confine their efforts to the ICTE industries. Next, the antitrust authorities need to identify a leading firm in the industry. There is no need to determine how the leading firm obtained its dominant position. Having a dominant position in itself is not a violation of antitrust law. The leading firm may have been successful due to its offering better products, better service, and lower prices.

By assuming or perhaps identifying the presence of network effects, however, the antitrust authorities can suggest that the dominant position is protected by technology lock-in. Finally, there is a need for competitors to request access to the leading firm's technology. Refusing such a request, or failing to comply, becomes the necessary monopolizing behavior that violates antitrust law. A dominant firm's refusal to supply access to technology to entrants and other competitors can also be identified as exclusionary behavior. Thus, technology lock-in justifies classification of refusals to supply access to technology as anticompetitive behavior. The result is that innovation and protection of intellectual property constitute anticompetitive behavior in markets that may exhibit network effects. Thus, technology lock-in mistakenly interprets vigorous competition by innovative firms as anticompetitive behavior.

Recall that interconnectivity or interoperability eliminate the problem of network effects that underlies the technology lock-in problem. Here again, failure to interconnect or to interoperate provides evidence of exclusionary behavior based on the technology lock-in view. The antitrust authorities need only establish that network effects exist and that products do not interconnect or interoperate fully. This relieves antitrust authorities from the burden of establishing either an intent to exclude or to identify exclusionary behavior. However, interconnection or interoperability can be costly so that it need not be socially efficient. Failure to provide full interoperability may simply be an efficient response to these costs by competitive firms, as was demonstrated earlier.

By requiring the standardization necessary for full interconnection or interoperability, antitrust authorities may discourage firms from creating new products. Consumers may benefit from product variety even with the potential loss of some network effects. The result of antitrust guided by technology lock-in again is stifling of innovation and reduction of product variety. Antitrust enforcement based on lock-in creates a self-fulfilling prophecy. Requiring technologies to interconnect or interoperate can restrict new technologies to be those that fit with existing technologies. The result is that technology lock-in occurs as a result of antitrust enforcement.

The focus on innovative industries as a source of exclusionary behavior is likely to be misplaced. Anton and Yao argue that constant and dramatic innovation, and large benefits from standardization should reduce antitrust concerns about high-tech industries. They further suggest that "[a]nticompetitive effects of interface standards are likely to be a matter of degree (raising costs differentially) rather than of exclusion."[112]

Hovenkamp argues that in network markets, cartels will raise prices, restrain innovation, and exclude others because firms will be more reluctant to defect from a cartel.[113] His argument is that a cartel enforces collusion by making technology standards available to members of the cartel. Those who do not participate in the cartel are excluded from the technology standard and must adopt a competing standard. Even if such a strategy made sense economically, this type of exclusionary behavior would not be very difficult to detect.

However, there do not appear to be economic returns to using technology standards for collusion. Network effects are reciprocal. Firms in the cartel would be harmed by excluding competitors from a technology standard. The customers of the excluded firms would be offered a competing technology. This would reduce the number of consumers who purchase the technology with the cartel's standard. The threat of exclusion is diminished if the effect of the exclusion is to harm the members of the cartel. The benefits to the cartel from the exclusion would need to exceed the effects of reducing the number of consumers who purchase the technology. In addition, the excluded firms would embrace a competing technology standard, which would strengthen the competing standard.

If there are network effects from embracing a common standard, firms will cooperate either by negotiating a technology standard or by licensing their technology. Myriad industry standards committees exist for all types of technological standards.[114] With many firms involved, the transaction costs of negotiating a standard are likely to be substantial. However, when benefits of standardization are sufficiently high, there may be returns to standardization through bargaining. Standard-setting organizations (SSOs) increase competition between firms within the standard. Mark Lemley argues that SSOs are an instrument of private ordering and suggests that antitrust policy may unduly restrict their activities.[115]

Standard-setting organizations involve coordination between the firms in the industry. Although this may involve smaller numbers of players in comparison with coordination between many consumers, the transaction costs of coordination within standard-setting bodies may be high. These costs are likely to increase if coordination is adversarial and if intellectual property rights are not well defined. Conflicts over intellectual property rights may

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[112] Anton & Yao (1995), *supra* note 63, at 263.

[113] Hovenkamp (2005), at 281.

[114] See www.consortiuminfo.org for a list of over 460 consortia, accredited standards bodies, and open source projects.

[115] Mark A. Lemley, *Intellectual Property Rights and Standard-Setting Organizations* (Boalt Hall, Working Papers in Public Law, UC Berkeley 2002).

lead to legal challenges to SSO patents.[116] There is evidence that SSOs are capable of selecting and promoting successful technologies.[117]

The alternative to cooperative standard setting is competition between standards. Standards competition provides a market test of alternative technologies. Even though a common technology standard provides benefits due to network effects, there may be greater benefits from competition. Firms offering competing technology standards have an incentive to improve the quality of the innovations. Competing standards are likely to represent substantially different technologies that offer consumers different tradeoffs in terms of product features.

Determining the best technology requires knowledge of how consumers evaluate the tradeoffs between product features. Individual consumers are the most qualified to determine their own preferences over product features. Accordingly, there is no effective substitute for a market test for differentiated technologies. Firms compete to promote a technology standard by employing a mechanism of spontaneous order, including prices, marketing, and sales. Hayek points out that "scientific discoveries have ample time to demonstrate their value." In contrast, economic competition "exhibits a method of discovering particular temporary circumstances." Market competition between technologies is necessary precisely because we cannot know the winner in advance. Hayek emphasizes that "competition is important primarily as a discovery procedure whereby entrepreneurs constantly search for unexploited opportunities."[118]

Technology alliances provide a middle ground between cooperative standard setting and competing standards. Firms within an alliance share a common technology and reap the benefits of network effects. Alliances compete with each other to establish a successful standard, thereby generating consumer benefits from competing prices and product improvements. The existence of such technology alliances in a wide variety of industries suggests that markets provide an efficient mix of cooperation and competition. The size of alliances reflects the tradeoffs between the benefits of common technology standards and the benefits of market tests of alternative technologies.

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[116] Simcoe et al. found that "SSO patents have a relatively high litigation rate, and that SSO patents assigned to small firms are litigated more often than those of large publicly-traded firms." T.S. Simcoe, S.J.H. Graham, & M. Feldman, *Competing on Standards: Entrepreneurship, Intellectual Property and the Platform Standard* (NBER Working Paper No. 13632, November 2007).

[117] *See* M. Rysman & T.S. Simcoe, *Patents and the Performance of Voluntary Standard Setting Organizations* (Boston University, Department of Economics Working Paper, June 2007). However, Simcoe found that the Internet Engineering Task Force (IETF) experienced a slowdown in standards production between 1993 and 2003 due to "distributional conflicts created by the increasing commercialization of the Internet during that time period." T.S. Simcoe, *Standard Setting Committees*, (Rotman School of Management, University of Toronto, Working Paper, December 2006).

[118] F.A. Hayek, *Competition as a Discovery Procedure*, 5 Q. J. AUSTRIAN ECON. 9 (Fall 2002).

VII. CONCLUSION

Markets can be expected to guide the adoption of technology efficiently. Consumers and firms will pursue their economic self interest in technology adoption decisions. Small numbers of consumers can easily coordinate their technology adoption decisions to take advantage of network effects. When there are large numbers of consumers, firms and other innovation intermediaries help to coordinate innovation adoption. A contracting environment that would produce network externalities is unrealistic. Absent such assumed network externalities, there are no market failures in technology adoption. Consumers and firms make efficient choices among products and innovations. As a result, technology is "unlocked."

The potential impact of network effects on technology adoption decisions is confined to the ICTE industries. These industries have developed market institutions that address such potential external benefits. As a result, the technology adoption biases ascribed to network effects have limited impact and should not drive public policy towards innovation in other industries. Evidence for lock-in is deficient, whereas innovation is abundant and continual. Innovation is a critical driver of economic growth and prosperity.

Even if it could be demonstrated that the economy was on the wrong path of technology adoption, is public policy the solution? Market adoption of innovations is a complex process in which individual consumers choose what products to buy, firms choose what products to supply, and inventors choose directions for R&D. As Schumpeter observed, entrepreneurs choose to innovate by making "new combinations," offering new products, production processes, and transaction methods.

Governments are notoriously inept at picking technology winners. Understanding technology requires extensive scientific and technical knowledge. Government agencies cannot expect to replicate or improve upon private sector knowledge. Technological innovation is uncertain by its very nature because it is based on scientific discoveries. The benefits of new technologies and the returns to commercial development also are uncertain. Friedrich Hayek emphasized that individuals have better information about conditions that apply to them and will be better at decision making than centralized government planners. Public policy makers lack the necessary information about the preferences of consumers, the objectives of firms, the ideas of inventors, and the insights of entrepreneurs.

The notion that markets get locked into inferior technologies would suggest that the government should replace clear winners in the marketplace with what government planners think would be superior technology. As a consequence, government planners may feel justified in pursuing industrial policies that subsidize specific technologies or protecting domestic industries against international competition from companies using distinct technologies. Government planners would be expected to solve the impossible problem of predicting technological change, as opposed to multiple competing technologies offered by markets. Government agencies are unlikely to reflect accurately the diversity of customer preferences about new products. The notion of lock-in has another dangerous implication. If markets are consistently locked into inefficient choices, then antitrust policy should target successful high-tech companies who presumably suppressed technologies offered by competitors.

The technology lock-in view is comparable to many other questionable justifications for government intervention in technology markets. Among these justifications is the recommendation that the government support innovative infant industries through industrial policy to protect firms from international competition as they try to catch up. Others assert that the government should set standards for new technologies because firms cannot coordinate standards. Some advocates of government intervention assert that public policy makers are better able than markets at identifying new technologies by picking winners. One recommendation that is connected to debates over patents and copyrights suggests that governments should strongly limit intellectual property rights in innovation so as to capture the benefits of public goods. Closely related to the network effects assumption is the traditional argument that governments should subsidize those innovations that have positive externalities, because markets may not adjust for the benefits of spillovers. Technology lock-in suffers, as does each of these justifications, from the danger that such government intervention will reduce incentives for innovation. This is the opposite of the intended result.

Antitrust policy towards lock-in risks causing the very problem that it tries to solve. Private sector experimentation is particularly valuable in resolving uncertainties in discovering and developing new technologies. Antitrust policy that targets successful innovators threatens to reduce such experimentation. By enforcing standardization, antitrust discourages the type of innovation that generates product variety. By requiring successful firms to disclose IP, antitrust damages incentives to innovate both for leading firms and for their competitors. By requiring compatibility, antitrust raises prices and costs, while discouraging the development of unique proprietary systems. By limiting the ability of successful firms to add product features and to bundle products, antitrust reduces incentives to improve technologies. Avoiding such misguided antitrust policies allows competitive markets to continue unlocking technology.