Chapter 5

What Does Industry Convergence Mean?

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Introduction

The Allegheny River forms in Pennsylvania, loops into western New York, and then flows southward into Pennsylvania. The Monongahela River forms in West Virginia and flows northward into Pennsylvania. At the very center of Pittsburgh, these two major waterways converge and become the Ohio River. Until they converge, geographers and everyone who uses them can distinguish them; where they converge, there is neither one nor the other but only a new thing: the Ohio River.

Industries that have been distinct historically, even as recently as a decade ago, converge in an analogous way. However, at the boundaries where formerly separate industries come together in a new industry, economic ambiguities arise. Ambiguity at economic boundaries is a sign of

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vitality in capitalist economies and has been a feature of the U.S. economy for some time. But, recent or not, convergence in evolving industries deeply affects the activities of the firms involved.

Ames and Rosenberg, describing the birth, evolution, and development of industries on the frontiers of technology at the turn of the century, introduced the concept of technological convergence.[1] This refers to the fact that a few broadly similar processes of production (e.g., using lathes and drills) were being introduced into a large number of industries (e.g., bicycles and automobiles). The same technical process gradually diffuses into a wide range of industries.

Addressing similar issues, Bresnahan and Trajtenberg use the related concept of general-purpose technologies to refer to technological systems that enhance the productivity of many industries. Rail transport, the steam engine, and machine tools are general-purpose technologies that, according to Bresnahan and Trajtenberg, have driven growth and market evolution in the twentieth century by diffusing into almost every industry with which we are familiar.[2]

The traditional literature on the evolution of industries has tended to look for industry life cycles and dominant designs.[3] Here, the emphasis is on the evolutionary pattern of an industry and how its development influenced that industry's growth, almost as though such patterns were preordained. Other authors have studied how the activities of individual firms influence the development of their industry.[4] However, when they discuss how and why firms change their activities, they focus on activities only within the relatively well-defined boundaries of the given industry rather than on what happens at the boundaries between industries.

We study the ways in which the boundaries between industries shrink or even dissolve to accommodate growth. In particular, neither the communications industry nor the computer industry can be understood unless we recognize that the boundaries between them are very fluid.

Our concern in this paper is with how the boundaries between industries evolve, especially those between computers and communications. Accordingly, we shall distinguish between two kinds of convergence, two different ways that the boundaries between the markets for computer products and the markets for communications products are dissolving. It is a given among professional observers that these two industries are converging. Our hope is that the analytic framework we offer will clarify what that means in a wide variety of examples.

The first four sections develop our analytical framework: first, we define the kinds of convergence; second, we consider the locus of convergence; third, we identify some economic effects of the different kinds of convergence; and fourth, we consider the motives for competitive and cooperative behavior that the kinds of convergence provide. The fifth section explores the usefulness of this framework by applying it to analyze one segment of the multimedia landscape: the evolving relationships between phone and cable companies. Last, there is a brief summary section.

The Kinds of Convergence

We suggest that there are two primary kinds of convergence: convergence in substitutes and convergence in complements.

Convergence in Substitutes

Two products converge in substitutes when users consider either product interchangeable with the other. Convergence in substitutes occurs when different firms develop products with features that become increasingly similar to the features of certain other products. It also occurs when firms develop standard bundles of components: common arrangements of components for performing a particular set of functions, as when a firm sees a keyboard, monitor, and central processing unit (CPU) as a complete system.

Think of the product (e.g, a word-processing software program) as being used in a variety of tasks: writing reports, developing bibliographies, and composing correspondence. These different tasks use different features of the product to different extents. Each user can therefore use the product for one, two, or all of these tasks. Thus, when a firm changes certain features of a familiar product, those developments might have very different effects on different users and/or on different tasks. In time, products that become more and more similar will be viewed by users as being increasingly substitutable for one another. Users buy one or another complete system because they consider that any one of the systems can do what any one of the others can do.

So there are two ways that products converge in substitutes (can be used interchangeably). First, a given set of users might be willing to use the two products as substitutes in an increasing number of tasks. And second, an increasing number of users might begin to think of the products as substitutes in a given set of tasks. Products that are becoming increasingly substitutable can, but do not have to, follow the same technical trajectory to achieve greater substitutability. More frequently, the products are unrelated at one time, but develop their increased substitutability over time, as the history of computing platforms shows.

Until the late 1970s, the mainframe and minicomputer industries were distinct. Mainframes and minicomputers were sold to different customers and served different purposes. Roughly speaking, mainframes were for commercial general-purpose use and for sophisticated mathematical computations. Minicomputers were for controlling repetitive processes and were dedicated to single tasks. Technical innovations in the mid-1970s blurred these distinctions, allowing minicomputers to perform multiple tasks simultaneously. Thus, manufacturers of mainframes and minicomputers could increasingly compete with one another for users of powerful, large-system computers. In this way, markets that were less related in the 1970s were increasingly brought into contact in the early 1980s.[5]

Convergence in Complements

Two products converge in complements when the products work better together than separately or when they work better together now than they worked together formerly. Convergence in complements occurs when different firms develop products or subsystems within a standard bundle that can increasingly work together to form a larger system. The output from the system can potentially be greater than the sum of the parts, that is, each component raises the marginal product of the others. This happens when the components together perform a new function that neither can do alone (e.g., an alarm and a timer together form an alarm clock). As with convergence in substitutes, there are two ways in which products converge in complements (can accomplish more together than separately). First, a given set of users can find that two products work better together for a larger set of tasks. Second, an increasing number of users can find that two products are complementary for their specific purposes.

As with convergence in substitutes, the products are often unrelated at one time and then converge in complements (develop complementarity) over time. The first PCs were used in the late 1970s by hobbyists in the home.[6] Apart from the hobbyists, PCs were first employed as essentially intelligent terminals in large business applications, that is, as complements to the existing mainframes. They were used for very simple programming tasks and for very minor processing before the main computations were sent back to the mainframe or the minicomputer.[7] Thus, there was little overlap in the tasks performed by PCs and those performed by more powerful computers.

The first users of the PC—engineers, hobbyists, or professional computer personnel with some training—had some complementary assets in place that allowed them to reap the benefits of the PCs. They had either a mainframe or supermini computers. These early users were later outnumbered by less technically sophisticated generalists. PCs evolved to be used for three major applications in the early-to-mid-1980s: word processors, databases, and spreadsheets. From the mid-to-late 1980s, PCs were being used for more general-purpose and business applications.

Another example of convergence in complements is the comparatively recent development of on-line databases. These products employ both advanced on-line transaction computing technology (e.g., hardware architecture and software) and data compression methods for telecommunications. The combination of two new technologies delivers a quasi-automated service that did not even exist in the 1960s.

Levels of Analysis and the Kinds of Convergence

Having distinguished between convergence in substitutes (interchangeability) and convergence in complements (use in concert), we now point out that, depending on the level at which a computing system or a communications system is analyzed, a particular instance of convergence may be construed as being of either kind. It may be interpreted as a convergence in substitutes at one level of analysis and, equally appropriately, as a convergence in complements at a different level.

An operating system (e.g., DOS) may be a complement to a particular hardware platform (e.g., a 486 Intel chip). It may also separately be a complement to another hardware platform (e.g., a Pentium chip). However, at the level of the system (the operating system plus the hardware platform), the different combinations of operating system and platform are substitutes for each other. A change that enhances the complementarity of the relationship between the operating system and either the 486-based computer or the Pentium-based computer may also enhance the extent to which the two systems are viewed as substitutes for each other.

Examples of a similar flavor abound. Local area network (LAN) communication protocols developed the ability to attach PCs using either the DOS or the Apple operating system. At the level of the individual operating system and the LAN, PCs using either DOS or System 7.5 converge in complements: each is able to raise the other's marginal products. However, at the level of the overall system (LAN plus operating system), there is a convergence in substitutes: the DOS operating system attached to a LAN is now seen as equivalent (in more respects than before) to an Apple operating system attached to a LAN. Thus, a convergence in complements at the level of the components is analogous to a convergence in substitutes at the level of the system.

Now reconsider the evolving relationship between PCs and minicomputers and mainframes. Ironically, though the PC was a complement to larger platforms in the early years, it has now become a substitute for those platforms for many uses. Shifts in the user base, combined with a rapid rate of continuing technical development in mainframes and PCs, have brought large and small platforms into competition for a variety of uses.[8] PCs today are diverse enough to compete for the same users that previously had small minicomputers or workstations. Many tasks, for which one would use only more powerful computers several years ago, are now performed equally well by PCs. Even more dramatic is the coming competition with large platforms. The promise of client/server technology—linking PCs together—now offers a substitute for large mainframe platforms.

Think of an ensemble of tasks that have to be performed (e.g., accessing, updating, reading large databases). At a point in time, the mainframe is unambiguously better for some tasks, the minicomputer for other tasks, and the PC for others, while they are considered equally suitable for the remaining tasks. Thus, at the level of the individual task, the mainframe and minicomputer are often substitutes. However, at the level of the ensemble of tasks, the mainframe and the minicomputer and the PC are appropriately seen as complements. In time to come, we can expect that technological evolution will render the PC and the minicomputer and the mainframe substitutable for one another for an increasing number of tasks. At the level of the individual task, then, PCs and minicomputers and mainframes will have converged in substitutes. At the level of the system, there is also potentially a change in the degree to which mainframes and minicomputers will be seen as complements. For example, mainframes are better suited for organizationwide, centrally managed large databases, while minis are better suited for departmental computing. Thus a convergence in substitutes at the level of the components may be analogous to a convergence in complements at the level of the system, the mirror image of the situation for the PCs and the LAN.

These examples illustrate how the boundaries between otherwise distinct markets shifted in a short period of time. These shifts reflected changing relationships of substitution and complementarity between hardware and software. Mainframes and minicomputers, traditionally used for distinct purposes, became substitutable for a wider variety of tasks. PCs and more powerful machines, initially used very much as complementary machines, evolved into substitutes for one another for a variety of tasks.

Other Examples of Convergence

Two other examples of markets with shifting boundaries will display the usefulness of our distinction between convergence in substitutes and convergence in complements: the video game industry and customer-owned communication technologies.

The Video Game Industry. Historically, video game firms were not viewed as being in the same arena with computer and communication firms. A video game was a device that featured crude, cartoonlike animation and responded to a simple system of controls. Momentous changes in technology, in both hardware and software, made this industry a powerful illustration of the shifting relationships between firms competing in hitherto distinct industries. On the software side, video games provide content to companies eager to find more material to transmit to the homes of TV watchers. Whereas historically there was no meaningful relationship between cable companies and video game firms, today firms in each industry have assets that are useful to the other. The cable companies get content, and the video game companies can use the cable infrastructure to distribute their product more widely. In 1994, Time Warner and Telecommunications, Inc. (TCI) announced that they would test-market the Sega Channel (a Japanese cable company that transmits only video games) in the United States.[9] Subscribers who bought or rented special hardware would be able to download video games from the cable system.

Software developments also have brought video game firms into contact with the film and computer industries. Both the film and video game industries benefit from technological developments in visual effects, inspired at least in part by work being done at computer companies.[10] Silicon Graphics and the Industrial Light and Magic Unit of Lucasfilm are creating the Joint Environment for Digital Imaging (JEDI). Video games have begun to move away from their crude animation and are now using actual footage from films rich in special effects, like *Jurassic Park*. Both films and games are using computer-generated backgrounds and even what industry observers call synthespians (synthetic actors).[11] Thus, not only do we see increasing convergence in complements between the film and computer industry, on the one hand, but films and video games appear to be headed in the direction of sharing a number of features that are increasingly becoming substitutes for one another.

On the hardware side of the video game industry, Sega hopes to use the hardware required to play its own games as the hardware necessary to operate interactive cable TV systems in the future. The competition to develop set-top boxes that will endow televisions with intelligence of sorts has attracted at least two additional classes of firms: providers of operating systems and semiconductor producers. Using the hardware as a computer of sorts is not far-fetched. In Japan, such hardware forms the basis of the Nintendo Network. With Nintendo's 1988 launch of the Family Computer Communications Network System, users of its Famicom (Family Computer) video game system could use a modem to transform a cartridge into a terminal through which to access on-line services.[12]

Customer-Owned Communication Technologies. There is also a shifting relationship between computers and the infrastructure of the public telephone companies. Local-area networks (LANs) and wide-area networks (WANs) have always had to work together with the public telephone network to some extent. However, the boundaries between the customer's equipment and that of the local telephone company are no longer clear. This trend has antecedents in changing FCC policies, growth of markets that can equip customer premises, and the evolution of network technology. While it is difficult to identify a single catalytic event, the choices today contrast sharply with those of the 1960s when AT&T dominated all facets of the telecommunications industry.[13]

Today's large users have the option of designing their own network to suit their communication/computing needs and the idiosyncratic features of their organization. They can also determine the points at which they interconnect with the public network, not to mention where/how they connect with their own computing networks. To an increasing extent, a large organization may substitute out of one network owned by a public utility into another network (customer-owned or leased from a third party for some services). Thus, there is a convergence in substitutes between components of the network. At the same time, users' choices of where to place the boundaries between networks depend on the relative technological capabilities inherent in the networks, and on their ability to manage the interface between the networks—not a trivial task. Users must ensure that their local networks and the public network work together (whether on an ISDN line or using simple modem technology), and that the new complementarity remains reliable (possibly with a second line from a competitor that provides access on the local loop). These combinations of networks lead to many new services, a phenomenon that may be thought of as a convergence of complements at the system level.

Currently, internal buses in computers work much faster than does the telephone network, effectively decoupling computers from the network. However, the advent of broadband networks will likely reverse the current relationships between network speeds and computer speeds. It will then be feasible to conceive of a firm as part of a seamless network of computers. In fact, with complete digitization, some have suggested that the entire public switched network could effectively be a large processor.[14] The set of tasks uniquely suited to computer networks within a firm and the tasks suited only to the public network will change, as will the set of tasks that the two networks can perform equally well.

Convergence Along the Value Chain

While convergence of any sort is ultimately brought about by the actions of a collection of firms, we adopt the perspective that an individual firm can take the converging environment as given. From that perspective, we need to understand which of a firm's activities are affected by each kind of convergence. To help us understand firms' interactions with a converging environment, we rely on an analytical construct called the *value chain.*[15] This conceptual model construes a firm as a bundle of activities that collectively produce value for the end user. Broadly, we can think of the value chain as being divided into three stages: procurement, production, and distribution. Firms interact with each other in the converging environment at different points along the value chain. Convergence might occur in the production stage of the value chain. Customers may perceive a product (e.g., Dell's design of PC hardware) as becoming increasingly substitutable for another particular firm's product (e.g., IBM's design of PC hardware) or as increasingly complementary, as when customers increasingly used Dell's PCs in tandem with IBM's mainframes without difficult changes in their network. We can say, then, that Dell's PCs and IBM's PCs converge in substitutes at the production stage, and that Dell's PCs and IBM's mainframes converge in complements at the production stage.

Products can also converge at the procurement (preproduction) stage. Two products converge in substitutes at the procurement stage when, for instance, one input becomes interchangeable with another input, perhaps from a supplier who previously had limited geographic distribution or a restricted customer base due to government regulation (e.g., cable firms or local telephone firms). Two products may also converge in complements at the procurement stage when, for example, products are sold together as a bundled unit (e.g., suites of shrink-wrapped software applications).

Instances of convergence in substitutes and/or complements also occur in the distribution stage of a firm's value chain. A firm might decide to alter the distribution of its product. A convergence in substitutes at the distribution stage occurs as the firm increasingly distributes its product through a different, hitherto distinct, channel. Alternatively, the firm could increasingly use its usual distribution channel to distribute some hitherto unrelated product. In this case, a convergence in complements at the distribution stage has occurred. Either type of change would affect a firm's ability and willingness to continue using its old method of distribution. Of course, a firm could decide to alter its ways of distributing its product for reasons that have little to do with convergence in the distribution stage. For example, a convergence in substitutes or complements at the production stage might cause the firm to alter its use of existing distribution channels.

One example of convergence in complements in the distribution stage is provided by products that integrate data, voice, and video. New technologies for transmitting and compressing data now make it possible to transmit data, voice, and video in the same fashion (by digitizing them). Because these data streams can be manipulated easily, and because of the increasing bandwidth, it is possible to cater to individual tastes for video, voice, and data much more exactly. These firms are obviously reevaluating their traditional ways of transmitting their products as they find that a number of alternative distribution channels are beginning to look more substitutable for one another.

Convergence at one position in a value chain may well cause convergence in another position. Firms making products that serve identical functions (substitutes) or that are used in concert (complements) by a significant part of the customer base are more likely to use similar distribution channels for these products than for unrelated products. In this case, a convergence in substitutes or complements at the production stage of the value chain could well precipitate a convergence at the distribution stage. However, convergence in the distribution stage could also occur independently.

At first glance, there may seem to be a fourth stage at which products converge in the value chain: the stage at which barriers between distinct kinds of customers dissolve. If we were to speak carelessly here, we might be tempted to say that customer bases converge. But in fact that is simply another way of saying that the products are converging in substitutes or in complements at any stage of the value chain. Firms would not develop products that are interchangeable (converge in substitutes at the production stage) unless they had very good reason for believing that more and more customers would buy them interchangeably. Firms would not distribute their products in channels distinct from their usual channels (convergence in substitutes at the distribution stage) unless they believed that more and more customers wanted to buy those products in the new channel. Nor would firms develop products that work better together than separately (converge in complements at the production stage) unless they had good reason to believe that more customers wanted to use, and would therefore buy, the newly combined products. Nor, finally, would firms distribute their products in two or more channels or distribute two different products in the same channel (convergence in complements at the distribution stage) unless they knew or hoped that more and more customers were buying them in all these channels.

We might even be tempted to say that the enlargement of the customer base is a natural consequence of dissolving barriers between formerly distinct kinds of customers. But this manner of speaking, too, is merely another way of talking about the kinds of convergence at any of the stages. Firms would not develop products that are interchangeable unless they had good reason to believe that developing those products would cause more and more customers to buy them. (Readers can make out the parallel arguments for the kinds of convergence at each of the stages.)

Consider the case of TVs and PCs. PCs are unambiguously better suited for some tasks (for example, tasks involving keyboard input), but there is an increasing range of situations where the two devices are more interchangeable than they were before.[16] PCs are acquiring better video capabilities, and TVs are increasingly becoming more than just dumb receptacles for an incoming video/audio signal. Suppose that TV firms and PC firms were both selling separately to the same customer group (e.g., technically sophisticated home users). While these customers originally thought of the TV and PC as serving distinct purposes, they might begin to think of them as substitutes for one another. Suppose there is a second group of customers (e.g., beginning home users) that buys only a TV or a PC, but not both. Now that PCs and TVs are substitutes, customers in the second group are no longer content to restrict themselves to the manufacturers of TVs or of PCs; instead, they investigate the range of firms that provide both TVs and PCs. Customers of the PC firms now become customers of the TV firms as well, and vice versa. A convergence in substitutes has enlarged. But that merely says that when products are interchangeable, more and more people buy them interchangeably. Convergence of either kind at any stage is in fact the process of removing barriers between formerly distinct kinds of customers.

We might think of one kind of barrier as artificial: barriers that are set by public policy. Regulatory barriers provide captive customers to certain firms. When those artificial barriers are lowered or removed, formerly captive customers are free to buy from other firms. Here, convergence in complements and/or substitutes somewhere along a firm's value chain cannot enlarge the customer base until the artificial barriers between customers are lowered or removed.

The slow melting of monopoly restrictions in providing regulated cable and telephone services is leading to new service, which makes it the obvious example. Fluidity at the boundaries occurs throughout the telecommunications industry because the FCC and state regulators intervene in many aspects of telephone and cable. In addition, the history of antitrust problems leaves a legacy of restraint agreements, such as the Modified Final Judgment, the restrictions of which also are eroding with time.

Some Economic Consequences of Convergence

Despite the fact that the different kinds of convergence often occur in tandem, discussing them separately allows us to distinguish clearly between their very different economic effects, particularly the effects on market concentration.

Consider convergence in substitutes at the production stage. As products become increasingly substitutable for each other, more firms begin to occupy the same market. The TV and PC markets, for example, are now populated by firms that were formerly active in only one or the other market. Thus, there is a clear decline in market concentration in each of the formerly distinct TV and PC markets. Virtually every example of convergence in substitutes (that we know of) results in widening technical opportunities, enlarging the potential points of entry to a market and increasing its competitiveness. The form of this expansion will differ across markets, however. It can take the form of racing to extend the functionality of products.[17] It can also be a combination of extending and filling in the product space, which usually coincides with reduction in price/performance.[18] In either case, the set of products available to consumers expands, as does the functionality associated with those products.

Changes in market concentration that accompany convergence in complements at the production stage make a wholly different set of considerations relevant. Definitions at market boundaries are often unclear in this situation because the markets themselves are still taking shape. The

products await development of new components and of system integration tools, and the standardization of interfaces. Convergence in complements is a situation rife with technical uncertainty, since incremental technical change usually arrives slowly, from many sources, and with many failures before commercial success is widely realized.[19] Moreover, the rate and direction of technical change depend on whether standards are fixed and known. We observe rapid rates of technical change if technically complementary products are easy to produce, as when standards are easy to adopt. We observe slower improvements if technical standards are not well defined and raise so much uncertainty that no one can easily design new components.

Furthermore, the ownership of property rights to the technologies that enable components to work together raises critical issues for the long-term development of market structure. If technical standards are open, in the sense that nonproprietary technical standards exist and are widely used, then the industry is likely to become competitive as new vendors of components enter (e.g., PC component manufacturing). The locus of competition will be at the component level, as opposed to the system level. This is the pattern of the PC industry, where multiple specialist firms compete to provide different components for systems (e.g., disk drives, monitors, coprocessors of various kinds, software add-ons, etc.). Buyers wanting to customize these components for their own needs can purchase all of them not only from the provider of the overall PC product but also from independent component manufacturers.[20]

If, on the other hand, technical standards are closed, in the sense that a single firm owns proprietary rights to widely adopted standards, then market evolution depends on the strategies of the owner of the standard. The owner of technology may choose to limit entry into complementary component markets because exclusive knowledge of the technology can be used to maintain competitive advantage (IBM used this strategy to enhance its dominance in the markets for peripherals for mainframes). The owner of the technology may also provide and support a complete integrated system. This strategy may make the owner resist outsourcing any part of the system (this is the traditional model for large computer manufacturers).

Proprietary owners also may license out their technology liberally, inducing makers of subcomponents to support their standard. Such vendors have decided to make their revenue in only a few choice parts of the value chain. Owners of a technology also may intentionally design their products without proprietary features, effectively inviting entry into subcomponent markets.[21] We can also say that the strategy of the owner depends on market structure, potential competitors' reactions, legal restrictions, and many other factors. Therefore, where proprietary standards are important, it is especially difficult to predict dynamic market behavior associated with convergence in complements.

Convergence in substitutes at the distribution stage also changes market concentration. On the one hand, more firms now use the same distribution channel. For a given capacity of this channel, the price per unit of capacity rises. One possible outcome could be a shakeout among firms that had used the channel, now that they face higher distribution costs. The leaving of some would increase market concentration. On the other hand, the fact that more firms, which used a different channel in the past, now use a common channel implies that the costs of distribution have fallen for them (otherwise, they would be less likely to switch to the new channel). One can imagine a greater number of firms in equilibrium in this industry, with a corresponding fall in market concentration.

Convergence in complements could also occur at the distribution stage. Complementary technological developments might result in an increase in the capacity of the distribution channel. If there is excess capacity, one can imagine that the costs of distribution to all users would fall (by an amount that depends on the distribution of property rights among the owners of the channel capacity). Equilibrium concentration might then be lower.

Cooperation, Competition, and the Kinds of Convergence

Depending on the nature and location of convergence, incentives for cooperation and competition will differ. Some kinds of convergence afford greater motives for competition, while others favor cooperation. In discussing the implications of various kinds of convergence for a particular firm, we adopt the perspective that the firm is not vertically integrated into its procurement or distribution stages.

We group motives for cooperation into two broad categories. First are the resource-based explanations. Within this category, firms cooperate to (a) benefit from diverse knowledge bases, (b) access financial resources, or (c) access tangible nonfinancial assets. They may also cooperate to find use for existing infrastructure. The second category includes more dynamic explanations for cooperation. Firms cooperate to influence the way a particular standard emerges. They may form alliances, or they may

invest in organizations that develop standards, or they may arrive at de facto cooperation on standards as a result of implicit agreements.[22]

Consider convergence in substitutes at the production stage. Since firms are pitted against relatively unfamiliar rivals, this kind of convergence is most likely to lead to increased competition. There are no resource-sharing incentives to cooperate.

All the action here is on the competitive front, and thus vendors may be easily blindsided. Any incentives to cooperate, if they exist, have to do with collusive arrangements designed to protect the value of existing resources in an industry filling up with new players. There are also incentives to (partially or fully) vertically integrate in order to control scarce distribution capacity or to access scarce production resources. Consider, for example, the following scenario: Product A now has functionality that brings it into competition with product B. Firm B is vertically integrated in distribution, firm A is not. Firm A will now have incentives to integrate distribution of product A to match product B, particularly if consumers are more familiar with purchasing product B in one location where A is not usually found. Similarly, if production of both A and B relies on scarce productive resources, there are incentives for firms to backward-integrate to control this resource.

Convergence in substitutes represents one of the most celebrated aspects of creative destruction: the unanticipated invention of entirely new ways of achieving a product of economic value. We wish to echo an observation often made by economists of industry evolution: it is generally in society's interest to keep open channels for developing and commercializing new ideas that threaten established products and ways of doing business. Since no firm likes to find itself in such an uncertain environment, all firms have incentives to cooperate in order to discourage (or slow down) rates of change.

With convergence in complements at the production stage, resource-based motives for cooperation abound, as firms seek to combine their assets in mutually advantageous ways that were hitherto impossible. Firms' knowledge assets are likely to change in value as component functionality expands. Therefore, firms scramble to enhance the value of subcomponents that may contribute to a greater system. However, this is easier said than done. It requires close monitoring of technical developments and changes, and, by its nature, is very speculative.

Among dynamic reasons for cooperation, the clearest is the need to influence the shape of future standards, either to gain proprietary rights over them or to prevent rivals from doing so. Firms also may turn to cooperative mechanisms in an attempt to prevent being blindsided, a situation that arises if a firm does not perceive the utility of a potential complement and is preempted by a faster rival. Firms turn to alliances with potential component manufacturers to resolve these uncertainties. These alliances, as well as standards development organizations, provide forums for transmitting information and for coordinating decision-making on the design of complementary components.

On the competitive side of convergence in complements, there is room for a new kind of competitor. There is typically a large market opportunity for system integrators because of the considerable added value associated with making products work together (e.g., LAN system integrators today). Incentives to vertically integrate exist, but for different reasons than those in convergence in substitutes. Here, the motive is to control access to a scarce product that might be used with one's own product.

The public policy concerns connected with convergence in complements center on two related issues. Since property rights or standards may play a large role, convergence in complements gives rise to exclusionary behavior when competitors form an alliance. Second, alliances and organizations that develop standards can play a very healthy role when there are dynamic reasons for cooperation. Government policy should encourage the healthy aspects of cooperation while preventing the exclusionary aspects. As illustrated by the recent interaction between Microsoft and the Department of Justice, such trade-offs are likely to be a concern of public policy for some time to come.

The overall effect of convergence in substitutes and/or complements at the distribution stage is to raise or to lower the capacity of the distribution channel relative to the number of firms seeking access to it. Thus, with convergence in substitutes, firms that had hitherto used distinct channels now find it possible to use the same channel, potentially creating a scarcity of channel capacity. However, if there is an accompanying increase in channel capacity owing to convergence in complements, there may be a resultant surplus of channel capacity. In either case, there is room for cooperation between firms operating at different stages of the value chain, with the relative bargaining power of the firms and their channel providers varying according to the extent to which convergence has created channel scarcity/surplus.

Following removal of regulatory barriers, the situation may take on the characteristics either of convergence in substitutes or of convergence in complements. In general, removing regulatory barriers forces incumbent firms to evaluate their core assets. They may invest heavily in

these assets to combat new substitutes, or they may be compelled to enter into alliances designed to protect these core assets. One additional implication favoring collusion between firms deserves mention. Theoretical work and empirical analyses specific to the airline industry have established that as firms face each other in multiple markets, the threat of retaliation against a firm initiating aggressive competitive tactics is magnified, leading to a reduction in such behavior.[23] As regulatory barriers dissolve and firms begin to face each other in multiple markets, the prospect of retaliation may blunt the effect of increased competition.

Several implications result from this analysis:

- Not all types of convergence increase incentives for cooperation. For example, convergence in substitutes usually decreases them.
- Many kinds of cooperation have little to do with convergence, but many motives for cooperating are misunderstood without understanding convergence.
- Competitive blindsiding is likelier because of convergence in substitutes. Firms may also be blindsided by convergence in complements if new functionality results and has broad appeal.
- Convergence in complements gives rise to exclusionary behavior when competing firms form an alliance and exclude one or more other competitors. Otherwise, cooperation among firms should be encouraged in markets undergoing this type of change.
- Government has two opportunities to change the rate and direction of convergence. First, it can influence the removal of regulatory barriers. The recent redefinitions of restrictions on the lines of business of local telephone exchanges is an obvious example. Second, government may or may not influence the use of alliances and mergers.

Applying the Framework

To explore the usefulness of our analytic framework, we have chosen to apply it to an open question of great importance: how the various pieces of the much-heralded information superhighway will end up relating to each other. First, we sketch out a simplified map[24] of a cross section of the superhighway, then we use our distinctions between the kinds of convergence to examine the collaborative agreements being signed between telephone and cable companies. We especially try to make sense of some of the newsworthy strategic and policy implications that arise from these cooperative agreements.

Information Superhighway: Sketch of a Cross Section

There are three types of actors in this cross section. At one end of a chain of events are the content producers (Hollywood studios, retailers, video game producers, educational software producers). In the middle, this content is distributed through AT&T's nationwide long-distance network or some other medium. We call this segment transmission stage interaction (TSI), referring principally to the interaction between the telephone and cable companies and the computer network providers. Finally, there is the reception stage interaction (RSI): the competition and cooperation going on between firms that try to create ways to help the end user navigate through the influx of data. How are these firms organized, and what will they sell?

At the content-producing end, firms such as AT&T and others propose to act as clearinghouses for these data by building networks of digital storage devices around the country that will store and update all the content. While it is not yet clear what information will make up most of the content in the commercially successful networks of the future, most of the incipient experiments include such things as new services, airline and entertainment schedules for local areas, government statistics, online search networks such as Nexus and Lexus, E-mail bulletin boards, and any digital information that a consumer might want to download from the World Wide Web: books, pictures, musical performances, movies, even an exercise video.

In the middle, TSI is concerned with the common agenda of transmitting information to the end user. Historically, cable companies have transmitted video, phone companies have transmitted voice (and data through modems), and computing network providers and system integrators have found ways to attach their networks to existing telephone networks. However, three classes of technological developments (data manipulation and compression techniques from the computer industry, developments in fiber optics, and advances in digital switching technology) have made it technically feasible for cable and telephone companies to transmit all kinds of data, blurring the technological distinction between a network/system integrator and a telecommunications/cable firm. Only government restrictions continue to preserve traditional separation between these products.

At the far end, variations on the appliances that will be used in navigating the information highway are available: personal digital assistants (PDAs) such as Apple's Newton, newfangled digital TVs, videophones, variations on video game players, and personal computer software. It is not yet obvious which of these devices will dominate, whether one or many will dominate different types of activities, or whether any of them will acquire commercially profitable extra capabilities.

What makes these developments so unpredictable is that it is not clear how they will all fit together in delivering a final product. From the consumer's standpoint, there is still little more than confusion, interrupted by the introduction of an occasional new product or toy with benefits that are exaggerated and a use that is not quite as easy as indicated. From the vendor's viewpoint, speculation and betting run high because design and operation decisions at one stage have consequences for design and operation decisions at other stages. Moreover, even though there are few customers today, decisions today may influence the direction of technical change for years, freezing out the slow movers. Whoever wins TSI will have a big say in the hardware device that wins RSI.[25] Thus, it is no surprise that computer companies involved in RSI have begun to form alliances with players involved in TSI, and vice versa: each wants to influence the other.

Collaborative Agreements and the Kinds of Convergence

The collaborative agreements that phone and cable companies are currently signing with one another can easily be understood in light of the motives provided by the kinds of convergence we have distinguished. First, convergence in substitutes at the production stage has already occurred. There is no longer any meaningful technological distinction between each firm's ability to carry voice and data transmissions.[26] Moreover, the lowering of regulatory barriers opens up opportunities for both types of firms. Phone companies want to benefit from the experience that cable companies have with accessing home users, while cable companies, desiring to introduce interactivity to film-watching, are increasingly interested in the experience of phone companies with switching technologies. Thus, each each type of firm's knowledge assets can potentially be utilized more effectively in concert with the other type of firm's knowledge assets, a case of convergence in complements at the production stage.

Second, there is also convergence in substitutes in the distribution stage. Phone companies want to collaborate with cable companies. This convergence arises from the fact that both voice and video can now be transmitted using the same distribution channel. Currently, local phone companies receive 90 percent of their profits from wired phone service.

Because they realize that people are switching to wireless communication, their partnership with cable companies is at least partially motivated by the hope of keeping their land lines humming with all kinds of interactive services.

A third reason for the collaboration has to do with getting around regulatory barriers. Historical regulatory regimes have forbidden phone companies from operating in each other's geographic territories. However, local Regional Bell Operating Companies (RBOCs), through their alliances with cable companies that have subscribers all over the country, can access rival phone companies' territories as well. Thus, their cooperation is an indirect way around the restrictions on customer base overlap placed by the regulatory framework.

Of course, this is a simplification of the particular set of reasons that might underlie a given collaborative agreement between a phone company and a cable company. Currently, there appear to be at least two approaches to collaboration taken by cable companies.[27] The degree to which a particular kind of convergence is important varies according to the approach. One approach is exemplified by Time Warner, which has allied itself with an RBOC (US West) and has chosen to stay away from wireless telephony. Instead, it focuses on developing selected telephone markets, an approach at least partially influenced by the heavy concentration of its cable subscribers. US West provides technical expertise and funds to help Time Warner upgrade its cable wires for local phone service. The second approach is exemplified by cable companies, such as TCI, that are betting on wireless. Thus the long-distance phone company Sprint, along with TCI and other cable companies, is trying to develop nationwide cable, local, long-distance, and wireless services.

Some crucial public policy issues underlie this situation. First, it is hard to imagine that a free hand for cooperative agreements between phone companies and cable companies is the appropriate policy. Part of the motivation of the participants in cooperative agreements is to protect the value of existing infrastructure, as when all firms try to stave off the competitive consequences of convergence in substitutes. If that occurs at the expense of slowing a general move away from wireline and toward wireless communication, probably the end users and society as a whole will suffer the consequences. We are certainly not the only observers to note this. However, efforts to delay the onset of convergence in substitutes is one of the main policy dangers here.

Second, the emergence of technical standards in one of or both TSI and RSI raises a public policy question. Our framework has an implication for this debate. Cooperation among firms developing technical standards

should receive flexible antitrust treatment when there is no danger of exclusionary behavior. For example, cooperative cross-licensing arrangements between close technologies should be encouraged by the FCC and related government bodies, particularly in the absence of well-defined standards.

However, our framework identifies the key policy conflict in this environment. There is a public interest in fostering cooperation that leads to development of new standards for the purpose of developing new products—the more convergence in complements, the greater the technological advances we are likely to see. However, it is not uncommon for new products to embody proprietary technologies that discourage cooperation between firms. On the one hand, proprietary standards enhance the returns to new technology and the likelihood of new product development. On the other hand, they delay the convergence in complements that leads to greater cooperation from different RSI and TSI vendors. We think that this conflict is endemic to convergence on the information superhighway and that government actions, either good or bad, can alter the outcome of this conflict. Unlike some of the more polemic trade press (about government policies in converging industries), our analysis shows why there is no simple solution: either much intervention or none at all. Sometimes government intervention, principally by the FCC or Justice Department, will be justified solely on theoretical economic grounds and sometimes not; the economic merits of this intervention must be weighed in a case-by-case basis.

Finally, it appears that barriers between customer bases will inevitably dissolve. Artificial restraints on this eventuality will merely succeed in delaying its realization, because firms will continue to expend valuable resources to find ways around the restraints. We see few public policy reasons for this delay except, perhaps, to foster the development of standards for interconnection at local telephone exchanges. Aside from this one issue, most of this goal was enhanced by FCC-mandated standards in the customer-premises equipment market several decades ago, and there seems to be little scope for similar action by the FCC today.[28]

Summary

This essay identifies two distinct types of convergence—convergence in substitutes and convergence in complements—and stresses the importance of appreciating where, in the chain of activities of a firm, the convergence occurs. In explicitly focusing attention on the different ways in which industry boundaries may be fluid, we move away from the traditional focus of studying evolution within well-defined boundaries. We have tried to clarify when these different kinds of convergence might occur together, and have argued that, despite this, the analytical distinctions are important inasmuch as they help us identify very different economic effects. In particular, firms' incentives for cooperation and competition differ quite extensively, depending on the nature and location of convergence.

Throughout, we are concerned primarily with firms' responses to convergence of different various kinds and, peripherally, with policy implications that influence those responses. While we have focused on understanding firms' reactions to different kinds of convergence, the influence of firms' actions on the nature and location of convergence deserves much more attention, as does the issue of how individual firms shape the boundaries of their industries.

NOTES

1. See Edward Ames and Nathan Rosenberg, "Technological Change in the Machine Tool Industry, 1840–1910," in Nathan Rosenberg, ed., *Perspectives on Technology* (Cambridge: Cambridge University Press, 1977).
2. Timothy Bresnahan, and Manuel Trajtenberg, "General Purpose Technologies: Engines of Growth?" *Journal of Econometrics* 65 (January 1995): 63–108.
3. See, for example, W. J. Abernathy and James M. Utterback, "Patterns of Innovation in Technology," *Technology Review* 80, no. 7 (1978): 40–47; Kim B. Clark, "The Interaction of Design Hierarchies and Market Concepts in Technological Evolution," *Research Policy,* 14, no. 5 (1995): 235–251.
4. See S. Klepper and E. Graddy, "The Evolution of New Industries and the Determinants of Market Structure," *Rand Journal of Economics* (Spring; 1995): Marco Iansiti and Tarun Khanna, "Technological Evolution, System Architecture, and the Obsolescence of Firm Capabilities," *Industrial and Corporate Change,* 2 (1995); and Tarun Khanna "Racing Behaviour: Technological Evolution in the High-End Computing Industry," *Research Policy* 24, no.6 (1995): 933–958).
5. See Timothy Bresnahan and Shane Greenstein, "Technological Competition and the Structure of the Computer Industry," CEPR Discussion Paper no. 315, Stanford University, June 1992, for further analysis.
6. Paul L. Robertson and Richard N. Langlois, "Modularity, Innovation, and the Firm: The Case of Audio Components," in Frederic M. Scherer and Mark Perlman, eds., *Entrepreneurship, Technological Innovation, and Economic Growth: Studies in the Schumpeterian Tradition* (Ann Arbor: University of Michigan Press, 1992).

7. Andrew L. Friedman and Dominic S. Cornford, *Computer Systems Development: History, Organization and Implementation* (New York: John Wiley and Sons, 1989).
8. See Iansiti and Khanna; and Bresnahan and Greenstein.
9. *Wall Street Journal,* March 15, 1994.
10. Salomon Brothers report, Global Equity Research Division, "Interactive Multimedia: When Worlds Converge," 1994.
11. See, for example, "Hollywood Scuffle," *Business Week,* December 12, 1994.
12. As of 1991, 130,000 users subscribed to its home shopping, banking, rail and air reservations, and stock brokerage services. A. Brandenburger, M. Burnett, and J. Kou, "Power Play: Nintendo in 8-Bit Video Games," Harvard Business School Case, 1995.
13. Eli Noam, "From the Network of Networks to the System of Systems, an End of History in Telecommunications Regulation?" *Regulation,* November 1993, 26–33; and Robert W. Crandall, *After the Breakup: U.S. Telecommunications in a More Competitive Era* (Washington, D.C.: Brookings Institution, 1991).
14. "The Future Surveyed," *The Economist,* Anniversary issue, 1993.
15. Michael Porter, *Competitive Advantage: Creating and Sustaining Superior Performance* (New York: Free Press, 1985).
16. Some of Packard Bell's multimedia computers come equipped with cable-ready TV, answering machine, fax, stereo radio, and CD-ROM drive (*Business Week,* January 9, 1995).
17. Tarun Khanna, "Racing Behavior: Technological Evolution in the High-End Computing Industry," *Research Policy* 24, no.6 (1995): 933–958.
18. Manuel Trajtenberg, *Economic Analysis of Product Innovation: The Case of CT Scanners* (Cambridge, Mass.: Harvard University Press, 1990).
19. Nathan Rosenberg, "Uncertainty and Technological Change," in Ralph Landau, Tim Taylor, and Gavin Wright, eds., *The Mosaic of Economic Growth,* (Stanford, Calif.: Stanford University Press, 1996).
20. See Robertson and Langlois.
21. For examples, see Paul A. David and Shane M. Greenstein, "The Economics of Compatibility Standards: An Introduction to Recent Research," *Economics of Innovation and New Technology* 1 (1990): 3–41; and Shane, M. Greenstein, "Invisible Hands and Visible Advisors: An Economic Evaluation of Network Standardization," *Journal of the American Society for Information Science* 43, no.8 (1992): 538–549.
22. William Lehr, "Standardization: Understanding the Process," *Journal of the American Society for Information Science* 43, no.8 (1992): 550–555.

23. See Douglas Bernheim and Michael Whinston, "Multimarket Contact and Collusive Behavior," *Rand Journal of Economics* 21 (1990), for theoretical work; and W. Evans and I. Kessides, "Living by the 'Golden Rule': Multimarket Contact in the U.S. Airline Industry," *Quarterly Journal of Economics* (1994): 341-366 for empirical analyses.
24. For another overview of the landscape, see Hagel and Eisenmann (1994).
25. Julio Rotemberg and Garth Saloner, "Interfirm Cooperation and Collaboration," in Michael Scott Morton, ed., *Information Technology and Organizational Transformation* (New York: Oxford University Press, 1992), provides a strategic analysis of these concerns.
26. For example, see Noam.
27. See, for example, "Now, Time Warner Is a Phone Company," *Business Week*, November 21, 1994.
28. See Crandall.

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