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Editor-in-Chief  
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TECHNOLOGY  
MANAGEMENT

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HANDBOOK  
CRCnetBASE

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## Innovation and Change

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## 3.12 Technological Convergence

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*Shane M. Greenstein*

Observers often interpret changes in the boundaries between firms and distinct industries as a sign of vitality. Given the label "convergence," well-known episodes have changed markets in areas as diverse as computing, medicine, communications, transportation, and retailing.

Convergence presents a challenge to technology management in the modern era. First, the diversity of market experiences motivates a great intellectual challenge. What framework helps analyze and organize the variety of patterns of change which accompany convergence?

Second, the diversity of experience presents difficult challenges for strategic management. Vendors must anticipate and respond to changes associated with convergence, such as changes in the identity of their competitors or changes in user's expectations about product functionality and price.

Accordingly, the literature on convergence is large, growing, and far from settled [Yoffie, 1997]. This review provides a basic overview of definitions and key issues. First, it classifies convergence into several categories [Greenstein and Khanna, 1997]. Next, this review highlights several issues of importance to anticipating the evolution of converging industries.

### Defining Convergence

Convergence describes a change over time. As the word "converge" suggests, convergence describes a tendency towards increased similarity or increased unification. It is the opposite of "divergence," a tendency to become less similar or less unified.

It is difficult to move beyond an intuitive description, making that definition both precise and general enough for many situations. Part of the difficulty is that two very different patterns comprise convergence. One pattern leads to making products interchangeable. Another pattern leads to making products better able to work in concert.

Two products converge in substitutes when market participants increasingly consider either product interchangeable with the other. This occurs when a product develops features that become increasingly similar to the features of other products. In contrast, two products converge in complements when the products increasingly work better together. In that case, the output from the system may be greater than the sum of the parts.

To begin the discussion, consider two examples. As noted by many observers, the modern PC initially performed most of the functions associated with an electric typewriter. At a simple functional level this was an example of convergence in substitutes. Another example that is also widely noted, modern medical imaging equipment such as an ultrasound or CT scanner marries advanced signal processing to many traditional sensor devices. This marriage of functions enables many new capabilities, which is an example of convergence in complements.

The creation of new capabilities is usually associated with both convergence in substitutes and complements to some degree. Both of the above examples contain this duality. The increasing replacement of the X-ray by the CT scanner or ultrasound is an example of convergence in substitutes. At the same

time, the CT scanner and ultrasound can perform many functions which were previously unobtainable with even the best X-ray technology. Similarly, while the development of word-processing on the modern PC made it a substitute for other typewriting equipment, at the same time the PC also developed new capabilities which old technology could not replicate, such as applications associated with spreadsheets and databases. These new capabilities meant that there was more occurring in the marketplace than just convergence in substitutes.

Convergence that influences business processes tends to simultaneously influence many parts of the value chain. Thus, they have consequences besides the simple replacement of existing processes with a cheaper alternative. For example, consider the check-out scanner as first seen in grocery retailing and then in virtually all retailing for standardized products. At its simplest level, the scanner arose through convergence in complements. It combines laser technology and database computing with advances in the theory of coding. A laser shines against the bar code, sending back an image which the sensor compares against a large database, sending information about the product back to the register.

Yet, in practice, the scanner also influences other organizational functions. In many instances, further information is passed to other inventory management systems, which, in turn, may be further passed on to upstream product and parts suppliers. The scanner enhances both the checkout function and inventory management processes, as well as replacing the need for clerks to look-up or memorize prices. It also enables a retail outlet to manage a greater variety of inventory and serve a greater volume of customers.

Because convergence often involves technically complex products, in some markets there is ambiguity over what users know and when they know it and whether products are converging at all. Thus, convergence, at least as it influences particular products, is difficult to measure. Similar issues arise in dating progress in the diffusion of new innovations through their life cycle. As such, the issues are not unique to convergence (see [Rogers, 1962]).

For strategic planning this ambiguity presents crucial problems. Many marketing plans and enterprise decisions depend on correct forecasting. The issue is particularly salient when technologies diffuse to different applications at different rates or diverge into diverse market segments.

For example, dual use technologies, which have application in both military and civilian markets, have historically either converged or diverged in somewhat unpredictable patterns. This pattern usually depended on whether the military subsidized developments primarily through broad R&D contracts to firms or through procurement programs for specific products. It also depended on whether military services required products with specifications similar to demands in civilian applications (e.g., on computing see [Flamm, 1985; Langlois and Mowery, 1997]).

Another example comes from the early history of computing. Though all applications were using the same basic science and technology, for much of the 1960s and 1970s the market for computing equipment diverged into three major niches based on the function of the system: (1) manufacturing, (2) business, and (3) scientific. Products in each field developed distinct functionality associated with reliability, ease-of-use, and servicing costs. Scientific computing often used advances in processing first, though some of the advances in programming and advanced architecture design eventually spilled over to other market niches. Manufacturing uses were often dedicated to the same task, and required little servicing from the vendors since the users were factory engineers. These divergent markets increasingly converged in substitutes in the late 1980s due to the PC revolution [Bresnahan and Greenstein, 1999].

## Convergence and Systems

The presence of a system is usually associated with both convergence in substitutes and complements to some degree. In other words, viewed in terms of its components and a system, convergence in complements and substitutes may occur simultaneously at the component level and at the level of system.

For example, an operating system (e.g., Windows) may be a complement to a particular hardware platform (e.g., an x86 Intel chip), together performing the functions of a server. At the level of the system, different combinations of operating systems and hardware may also perform similar server functions.

Hence, for example, at the end of the 1990s the Intel-based servers in a client/server architecture converged in substitutes with arrangements using older operating systems, such as mainframes.

The rise of the "network of networks" in the 1980s and 1990s complicated the analysis of convergence on different levels of a system. In networks linked by Internet protocols, convergence in both complements and substitutes arises from the cumulative actions of (potentially) different decision makers over time. This is because ownership over the necessary scope and breadth of technical and market expertise is widely dispersed among firms and users, raising the possibility for initiatives from many corners. It results in an evolution at the system level which is the cumulative outcome of many (potentially independent) episodes at the component level. The absence of parallel patterns at the component and system level may heighten the complexity of analysis and the degree of uncertainty associated with a particular episode of convergence in a network of networks.

For example, the first uses of the Internet were primarily for electronic mail and later for applications using the World Wide Web. The first developers and users of these capabilities were academic users and researchers. The limits on early use did not give analysts much precedent to predict developments in commercial applications, which exploded after the privatization of the Internet by the NSF. Commercial applications tended to emphasize the needs of less technical users. These new developments replaced some old methods for communicating, but also developed new media.

Convergence in a network of networks raises additional strategic and managerial issues. Convergence in complements on a network of networks has historically been associated with significant discontinuities in the competition for delivery, and the evaluation of the relative performance of, established products. This discontinuity arises due to the emergence of unanticipated capabilities for which there is little precedent. For example, the rise of electronic commerce using Internet protocol and Web-based media permitted a number of new business models. For many years after the commercialization of the Internet, it was unclear which business model would predominate and which established business, if any, it would favor.

Discontinuous change is not, per se, unusual in markets for technically complex goods. However, such discontinuity may arise due to independent initiatives from many providers of complementary goods, each of whom is independently marketing new capabilities. The independence of these initiatives reinforces the perception among established companies and market analysts that markets can change rapidly for reasons nobody, not even a seasoned expert, could anticipate. Thus, convergence in complements within a system of systems is often associated with extraordinary uncertainty about the arrival of convergence in substitutes on the market level.

Discontinuity in converging market presents special challenges for strategy. Firms are preparing for competitive situations within many undefined market parameters. This is market risk which cannot be reduced significantly; at best, management can prepare to respond to changes in external conditions by making strategic investments in information gathering, in tools for tracking market and technological trends, and in flexible organizational structures [Yoffie, 1997]. This environment also places a high value on "market makers" who learn how to mediate between the new possibilities and the (as yet unmet) needs of buyers [Spulber, 1998].

## **Convergence and Government Regulation**

As shorthand for describing convergence at a system level and for making predictions about market developments, analysts often ascribe causation for convergence to a small number of technological trends, such as improvements in microchips or fiber optics. This shorthand can carelessly acquire strong elements of technological determinism, which may fail to identify key mechanisms that shape events in converging markets.

Because so many communications and broadcasting systems across the globe involve significant government regulation of partially or wholly monopolized communications facilities, the rate and direction of convergence in networking applications often depends on regulatory and government decisions, not just technological feasibility and entrepreneurial commercial initiatives. Since so many important exam-

ples of convergence in the modern era involve communication technology, it is important to bring these factors into consideration (for example, see [Crandall and Waverman, 1995]).

For example, the convergence of wire-line and wireless technology in the U.S. depended on rules governing the development of analog cellular and digital wireless applications over the publically governed spectrum. Though the typical cellular phone may deliver a lower quality sound than experienced in land-line phones, it is still good enough for the human ear to discern. It partially replaces the traditional plain old telephone service over land-line technology (while also working with it), and also enables valuable mobile and convenient communications which the land-line technology could not provide.

In contrast, convergence in substitutes for alternative modes of long-distance voice transmission depended on rules opening long distance telephony to entrants using spectrum technologies other than land-line based facilities. Once these rules were changed in the U.S., for example, the long distance market seeded new telecommunications firms such as MCI and Sprint. A different set of rules continue to constrain similar initiatives in international markets.

More significantly for developments at the end of the 20th century, the revolution in customer premise equipment aided convergence in complements. A long series of court fights and FCC rulings over the 1950s, 1960s and 1970s developed rules which made it feasible for customers to easily attach their own equipment. This induced entry of new component designs from firms other than AT&T and its affiliates. The modern fax machine, modem, and PBX market all grew out of these government rulings. This opening of markets was important because many other attachments to the telephone network were not anticipated when these rules went into place; yet, these rules favored decentralized initiatives from many developers, a necessary precursor to the network of networks of the modern era.

## **Strategy and Industry Evolution**

Many managerial strategies depend on understanding how convergence changes firm behavior, buyer choices among vendors, and the locus of profitable opportunities. There are many ways to address these topics and it is not possible to provide a complete review. This discussion highlights three concepts useful for formulating strategies when a firms' business is significantly influenced by convergence at the system or market level. These concepts are general purpose technology, adaptation, and the platform.

### **General Purpose Technology**

Much technological convergence can be reinterpreted as the consequence of the diffusion of a general purpose technology, or GPT for short. Bresnahan and Trajtenberg [1995] define these as capabilities whose adaptation to a variety of circumstances raises the marginal returns to economic activity in each of these circumstances (See also [Ames and Rosenberg, 1984]).

GPTs tend to involve high fixed costs in invention and low marginal costs in reproduction. Invention of general purpose technologies, such as computer hardware and software, telephone transmission technologies, or database technology, are examples. These inventions and their refinement permit but do not compel further development of valuable uses. Thus, the emergence and diffusion of GPTs may underlie convergence, explain the presence of similar technological processes in a variety of applications and markets, but will not entirely determine its final shape in the market place.

Two examples illustrate many of these points: First, application software is supplied by firms who live at the boundary between the general purpose device, the computer or network, and the special purpose device, the business information system. This existence has been complex and the market structure has many unique features [Mowery, 1996]. Packaged software exists in only a few categories of applications. Most software is sold along with consulting services and other products such as hardware. Many new ideas are designed by lead users or academic researchers, communicated through research channels to lead programmers and designers, then incorporated into commercial products in a variety of formats over time. Hence, the benefits from this particular GPT are wide, but the experiences associated with each application are also quite varied.

Second, Internet technology is also not a single invention, diffusing across time and space without changing form. Rather, it is a suite of communication technologies, protocols, and standards for networking between computers. It alters the performance of a variety of complementary activities and is not useful by itself. Every extension of that suite to new uses opens questions about the adaptability of the technology. The value of the technology, therefore, depends on how it adapts to different computing environments, different computing applications, and different types of computing users.

### **Adaptation**

As this second example strongly hints, a commercialized GPT must be adapted to its new use — some might say “customized” to each new application — and such adaptation takes time and invention. One reason is that invention is a complex and unpredictable activity in its own right. Another, and not necessarily independent reason in the context of the IT revolution, relates to the many feedbacks between different investments associated with invention.

Adaptation services involve one of several activities: Monitoring technical developments, distilling new information into components that are meaningful to unfamiliar users, and matching unique user needs to one of many new possible solutions enabled by convergence. Sometimes adaptation involves heavy use of the technological frontier and sometimes not.

Adaptation does not happen on its own. The agents of change come from one of several groups: end-users within an organization, professional staff (such as the MIS group) within an organization, or third party vendors outside the organization. If the end-user or their staff does much of the adaptation activity, it becomes an extension of other operations and investments. In contrast, if third parties sell related services to users, it may arrive in several different forms, sometimes as equipment, sometimes as consulting about business processes, and sometimes as complements to both.

The rate and direction of adaptation activity is difficult to predict. No single actor can envision how the GPT should operate in all potential applications. Accordingly, when adaptation is valuable, such markets involve experimentation with new business models, new costs structures, and new applications. Different vendors take different approaches in translating and customizing general purpose technologies to the unique needs of users and their organizations, solving problems as they arise, tailoring general solutions to idiosyncratic circumstances. This activity helps users experiment, filling gaps between what convergence has made possible and what users find useful.

One example may illustrate these points. After the NSF officially privatized the Internet backbone, there was a commercial opportunity to take applications based on Transmission Control Protocol/Internet Protocol and translate it into commercial uses. This opportunity arose partly because the Internet had been specifically tailored to the needs of academic users and researchers prior to 1994. The particular needs of commercial users were decidedly different, requiring a range of activity from commercial suppliers of Internet services.

Adaptation involved the development of new goods that largely used existing Internet technology. Nonetheless, the redirection of those capabilities to new uses and users involved significant investment and commercial activity. Hence, convergence of old technologies with Internet-based applications of broadcasting, telephony, and new communications media depended on the characteristics and capabilities of those providing the adaptation services, their experience prior to the commercialization of the Internet, and particular needs of commercial users.

### **Platforms**

Platforms have historically played an important role as a coordinator of buyer and supplier adaptation activity. Platforms, such as the IBM System/360, the Wintel system, or the Apple Macintosh, share interchangeable components, so many sellers and buyers can share the benefits of the same technical advance and the same complementary adaptation activity. Interchangeable components also permit buyers to use the same platform over time, avoiding losses on long-lived software or training investments.

Different platforms have been organized and controlled by sellers in different ways. Sometimes, as in mainframe computers, a single platform, offered by a single firm with a high level of vertical integration

(IBM), dominates the translation of convergence into profitable opportunities. In contrast, in personal computers, the IBM PC platform was controlled at first by a single firm, but later decentralization led to the "Wintel" platform controlled by Microsoft and Intel.

Platforms shape competition and convergence in two distinct ways. First, there tend to be few platforms in any market segment. The fight for control of platforms, and fight to own the technical standard embodied in them, influences the strategies of the firms who seek to profit by using an existing platform to achieve convergence in complements in a particular instance. For example, the fight to control the Wintel platform formed the basic backdrop for many firm strategies during the existence of this platform.

Second, the competition between platforms often forms the backdrop for convergence in substitutes. In general, convergence in substitutes is rare among mature platforms. Long-lived investments generally lead to platform persistence and buyer resistance to change.

In their study of the development of the computing industry, Bresnahan and Greenstein [1999] argue that the increasing convergence in substitutes among computing platforms in the late 1980s arose partly in response to a breakdown of the competitive environment that had kept new platform entry from encroaching on existing applications. Client server computing became associated with new market opportunities for which many existing firms possessed appropriate commercial capabilities. This new competitive environment led to convergence in substitutes between the old and new platforms.

## Defining Terms

**Convergence in substitutes:** When market participants increasingly consider two products interchangeable with each other. This occurs when a product develops features that become increasingly similar to the features of other products.

**Convergence in complements:** When the products increasingly work better together. The output from the system may be greater than the sum of the parts.

**General purpose technology:** Capabilities whose adaptation to a variety of circumstances raises the marginal returns to economic activity in each of these circumstances. These types of technologies tend to involve high inventive costs but low reproductive costs.

**Platforms:** These standard bundles of components share interchangeable parts such that many sellers and buyers can share the benefits of the same technical advance and the same complementary adaptation activity. Interchangeable components also permit buyers to use the same platform over time, avoiding losses on long-lived software or complementary investments.

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