The Embeddedness of Technological Systems

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December 1997

Working Paper Series
Stern #IS-97-31

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ABSTRACT

Technological systems are shaped both by forces arising from the technical environment of product markets and those arising from the institutional environment of compatibility standards. We explore how it might be possible for standards to simultaneously enable activities in the technical environment and not constrain them. Such a scenario is possible when the technical environment is not completely embedded in the standards that shape them. We characterize such technological systems as being "just" embedded.

We are living in an era of unprecedented change. Every facet of our lives is constantly being affected. Almost daily, we are being introduced to a bewildering array of new technologies, some of which seemed unimaginable only a few years ago. Often, these technologies are incompatible with one another, and they sometimes become obsolete even as we buy them.

Advances in Strategic Management, Volume 13, pages 389-408.

ISBN: 0-7623-0010-8

The increasing importance that technologies are playing in our daily lives raises a crucial question: *How do technologies emerge?* Two forces identified as playing a key role in this regard are the "pull" of the market and the "push" from advances in science and technology (Comroe & Dripps, 1976; Myers & Marquis, 1969). Some researchers have suggested that both these forces play an important role, each shaping the other over time (Freeman, 1986; Mowery & Rosenberg, 1979).

Both the technology-push and market-pull viewpoints focus primarily on the product market domain and subsume the existence of an institutional environment (cf. Ruttan & Hayami, 1984). The institutional environment refers to the criteria for interpreting efficiency and effectiveness of activities in the technical environment of product markets (Scott & Meyer, 1983; Powell, 1991; Oliver, 1991). In this regard, Dobbin (1995) points out that what we view as a naturally occurring market is actually institutionally defined. Similarly, Constant (1980) demonstrates how the institutional environment of standards (one that he labels as "traditions of testability") powerfully influence product development activity in the technical environment (see also Garud & Rappa, 1994).

Institutional environments have an interesting paradoxical property. On the one hand, they are required for establishing stable technological expectations amongst vendors and users. Such stable expectations are essential for the wide spread diffusion of a technology (Rosenberg, 1976). On the other hand, once created, these institutionalized practices tend to focus activities in the product-market environment along particular "trajectories" (Dosi, 1982). In other words, institutional environments both enable and constrain activities in technical environments.

For instance, compatibility standards are a key institutional facet of most information technology based industries (Garud & Kumaraswamy, 1995). In these industries, common standards provide users and vendors with a platform to use and innovate upon. However, once set, these standards "lock in" users and vendors to particular trajectories, and at the extreme, prevent the technology from migrating to new functionalities (David, 1985; Arthur, 1988; Farell & Saloner, 1986).

How can technologies benefit from the coordination that institutional standards can provide while overcoming their constraining effects? We suggest that this can happen when the institutional environment of compatibility standards "just" embeds the technical environment of product markets.[1] By "just" embedded we mean that standards and the processes associated with them provide the coordination required to carry out technical activities in the present, and, at the same time, not constrain the migration of the technology to new functionalities in the future.

Observations from the computer networking field suggest certain key processes associated with a "just" embedded technological system. First, although compatibility standards shape activities in the technical environment, they do so in a loosely coupled fashion (Weick, 1976). Such loose coupling provides room for autonomous innovations, thereby creating paths for the technology to migrate to new functionalities. Second, processes exist for the incorporation of these innovations into the institutional environment of standards. In conjunction, these processes result in the unfolding of a co-evolutionary dynamic with the institutional and technical environments reciprocally shaping each other over time (Garud & Kumaraswamy, 1995).

THE NATURE OF TECHNOLOGICAL SYSTEMS

Technological systems comprise a set of components that together provide utility to customers. System performance is dependent not only upon the performance of constituent components, but also on the extent to which they are compatible with each other (Gabel, 1987, p. 93; Henderson & Clark, 1990; Garud & Kumaraswamy, 1993). Compatibility between system components can be achieved by designing them to a common set of standards. Standards are codified specifications that prescribe rules of engagement between components. Together, specifications about the form and function of components and the rules determining interaction between them define a system's "architecture."[2]

Scott and Meyer (1983) define technical environments as those in which a product or service is produced and exchanged in a market such that organizations are rewarded for effective and efficient control of their production system. Institutional environments, in turn, are those characterized by the elaboration of rules and requirements to which individual organizations must conform if they are to receive support and legitimacy. In a similar manner, we suggest that the technical environment of a technological system consists of innovations and performance enhancements at the product and component level that are eventually exchanged in a market. The institutional environment of a technological system consists of the mosaic of compatibility and performance standards that together constitute the architecture of the technological system. In this way, standards are to technological systems what institutional environments are to organizations.

The existence (or lack) of compatibility standards influence activities in the technical environment. Consider the early stages of technology development when commonly accepted standards do not exist. The absence of such standards results in entrepreneurs placing bets on different trajectories based on their beliefs of what will be possible in the future (Garud & Rappa, 1994). In this way the absence of standards fosters variations that are key to the future evolution of the technological system.

This lack of standards however, also results in high levels of ambiguity about which trajectory will eventually be successful. Confronting ambiguity, customers are likely to postpone the purchase of specific products thereby dampening the diffusion of the new technology (Rosenberg, 1982). Such an "anticipatory retardation" process, then, can prevent the rapid development of a technology.

Conversely, the presence of standards enables the evolution of a technology. Standards overcome anticipatory retardation on the part of users and create stable expectations between mutualistically interdependent firms. Such expectations are important for fostering innovation in complementary parts of the technological system. As firms innovate to a common standard, benefits from supply and demand side externalities also begin to accrue (Katz & Shapiro, 1985; Farrell & Saloner, 1986; Economides, 1996).

While standards enable developments in the technical arena, their presence comes at a price. Once institutionalized, the existence of standards constrains the development of the technology to certain trajectories. The path dependence and cumulativeness implicit in such a progression can sometimes prevent existing technological systems from migrating to new functionalities (Farell & Saloner, 1986; David, 1985; Arthur, 1988).

The enabling and constraining effects of standards on activities taking place in the technical environment can be represented by the framework in Figure 1.[3] A lack of standardization would be located at the bottom horizontal axis (marked as position # 4). In this position the absence of standards offers "open space," thereby not constraining the creation of new technologies. At the same time, activities in the technical arena are not enabled because of the existence of ambiguity and incompatibilities. In contrast, situations in which standards have been established are represented by the top horizontal axis (position # 3). Here, the presence of standards enables the development of the technology within a trajectory and allows for interconnectivity between components, but simultaneously defines and constrains the development of the technology.

Transitions between the bottom horizontal axis to the top horizontal axis can be understood in the terms of the two stage dominant design model of technological evolution (Utterback & Abernathy, 1975; Anderson & Tushman, 1990). During the early stages of ferment, the absence of commonly accepted standards fosters variations resulting in the creation of several competing technological trajectories, each with their own dimensions of merit (Tushman & Rosenkopf, 1992). However, confronting the ambiguity that is an integral part of this era, customers and vendors might be more prone to wait for the emergence of a dominant design before they are induced to make significant investments. Over a period of time, a dominant design emerges that constrains technical activity to certain trajectories. The emergence of such a selection environment, however, enables complementary innovations and product refinement—characteristics of an era of incremental change.

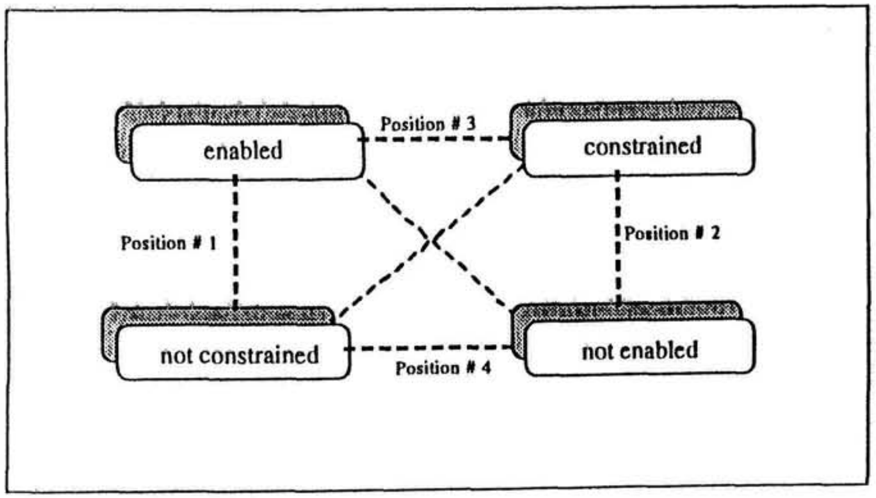

Figure 1. Enabling and Contraining Effects of Standards

Our framework allows for two additional relationships to exist between the institutional and technical environments of a technological system. Position # 2 represents a situation in which the technical environment is both constrained and not enabled by the institutional environment. Such a situation can occur if the institutional environment constrains the technical environment completely. In such a scenario, the degrees of freedom associated with a technological trajectory have been exhausted and yet it is impossible to shift to another trajectory because of the accumulated cognitive, institutional and technical sunk costs that have been incurred. A classic example of such a "stuck" technology is the QWERTY typewriter keyboard (David, 1985). Not only are users constrained from migrating to more efficient systems, there are few innovations taking place on the existing platform.

In this paper, we concentrate on the left hand side of the framework (Position # 1). In this position, the institutional environment "just" embeds the technical environment. Technological systems in this position are both enabled and not constrained—both connectivity between components (of the technological system) and the capability to migrate to new functionalities exists. Such technological systems are characterized by rapid change in both their technical and institutional environments, each of these reciprocally and continually shaping the other. This co-evolutionary mode of technology evolution lies in contrast to the imagery of the two stage technology cycle, in which the era of ferment is characterized by high levels of activity in the institutional environment and the era of incremental change is characterized by innovations in the technical environment.

We examine the evolution of computer networking technology to explicate the dynamics associated with a "just" embedded technological system (Position # 1 in our framework). The choice of this research site was deliberate. Over the past 15 years, there have been tremendous changes, both in the technical environment of product markets as well as in the institutional environment of standards associated with this field. Illustrative of changes in the technical environment is Moore's law that has successfully predicted the continued decline of semiconductor price to performance ratios (*Fortune*, July 19, 1995, p. 91). Moreover, the institutional environment of standards too has exhibited constant change. As networking expert Harald Alvestrand says, "The speed of standards change reflects the speed of change in the technology; in an industry where "normal speed" goes from 9600 bps to 45 Mbit/sec within 5 years, you can't expect the standards to remain constant" (Alvestrand, 1995).

COMPUTER NETWORKING: A HISTORICAL PERSPECTIVE

A Case of "Technology Indigestion"

For most part of their history, computers have been stand alone units performing data storage and processing functions. Advances in microprocessor technologies and the advent of personal computers have progressively reduced storage and processing costs. This, in turn, has allowed for the possibility of more decentralized computing paradigms and has brought about the emergence of network computing.

The historical legacy of computers, however, has left users with a bewildering array of systems (mainframes, mini's and PC's amongst others), manufactured by different vendors, each with their own specifications. As a consequence, the need to establish common standards that can enable communication between these disparate systems has become a key issue. Highlighting this concern, Scott McNealy, CEO of Sun Microsystems states: "The biggest issue the industry must confront is the desperate need to standardize...customers are suffering from a severe case of technology indigestion."

The Emergence of an Institutional Environment

Efforts to establish computer networking standards (or protocols, as they are referred to within the field) date back to the late 1960s. Academic researchers working for the U.S. Department of Defense Advanced Research Projects Agency Network (DARPA) built support for computer networks on the Transmission Control Protocol/Internet Protocol (TCP/IP).[4] Introduced in 1974, this low-cost connection mechanism designed to connect incompatible processors gradually gained adherents in government agencies and academic institutions, and began attracting commercial attention in the early 1980s.[5] However, industry consensus was that TCP/IP would be an interim standard, eventually giving way to a "more advanced" networking protocol. As a prominent networking specialist stated back in 1982: "TCP/IP was designed with a lifetime of maybe 5 or 10 years in mind. It will not be widely used outside DOD" (*Data Communication*, July 1982, p. 89).

IBM introduced a set of networking protocols, Systems Network Architecture (SNA) in 1974.[6] While products based on these protocol achieved interconnection within the homogenous realm of IBM's own computers, this solution still left unsolved the problem of enterprise-level interoperability. The use of SNA as a networking protocol meant that non-IBM computers could not communicate with an IBM machine as well as Big Blue could.[7] The proprietary nature of SNA thus constrained user freedom in implementing multi-vendor networking and created "islands" of computer connectivity.

A study carried out by the International Organization for Standardization (ISO) in the early 1970s anticipated just such a scenario. It concluded that if each manufacturer were to independently design networking protocols, either one dominant force would emerge, or, there would be a proliferation of incompatible solutions that would severely constrain the user community. The concept of Open Systems Interconnection (OSI) thus emerged with the charter to establish a sound foundation that would enable free interchange of information between computer resources and shape the future of data communications.

The OSI initiative, formally started in 1978, comprised two parts: (1) the establishment of a Reference Model, and (2) the creation of a specific set of protocols that could then be used by vendors for implementing their computer networking solutions. The ISO adopted the OSI Reference Model in 1984. The model detailed in abstract terms a seven-layer structure that allowed incompatible computer systems to communicate with each other (see Appendix).[8] The more challenging process of establishing specific protocols for each of the defined levels was to follow.

Institutional Dynamics: The Rise of TCP/IP

Twenty years later, each of these standards-making initiatives have had very different impacts on computer networking technology. OSI-based protocols were the promised panacea for technology indigestion through the 1980s. However, inordinate delays in OSI's standard-setting processes have ensured that products based on this protocol have had a minimal impact on the marketplace. SNA has fared much better, in part due to the large installed base of IBM computers at corporate user sites. And, most surprising of all, TCP/IP has emerged as a defacto computer networking standard. Its progress from a "down-and-dirty" network engineer's protocol to a mature standard that corporate information systems departments can trust with business critical applications has been nothing short of remarkable.

In Figure 2 we have plotted the number of yearly citations of the three protocols as they appear in the ABI-Inform database over the period 1986-1995. We use these figures as a measure of the "adaptive expectations" associated with each of these protocols (Arthur, 1988; Besen & Farell, 1994). Adaptive expectations, in Arthur's terminology, refers to a situation where increased anticipation of a standard—measured here in terms of yearly citations—enhances beliefs of future prevalence.

As Figure 2 indicates, expectations associated with the OSI initiative far exceeded those associated with TCP/IP and SNA right upto 1991. Since, there has been a dramatic drop in interest in the OSI initiative and a corresponding rise in TCP/IP's fortunes. The expectations associated with SNA have remained fairly stable through this time period.

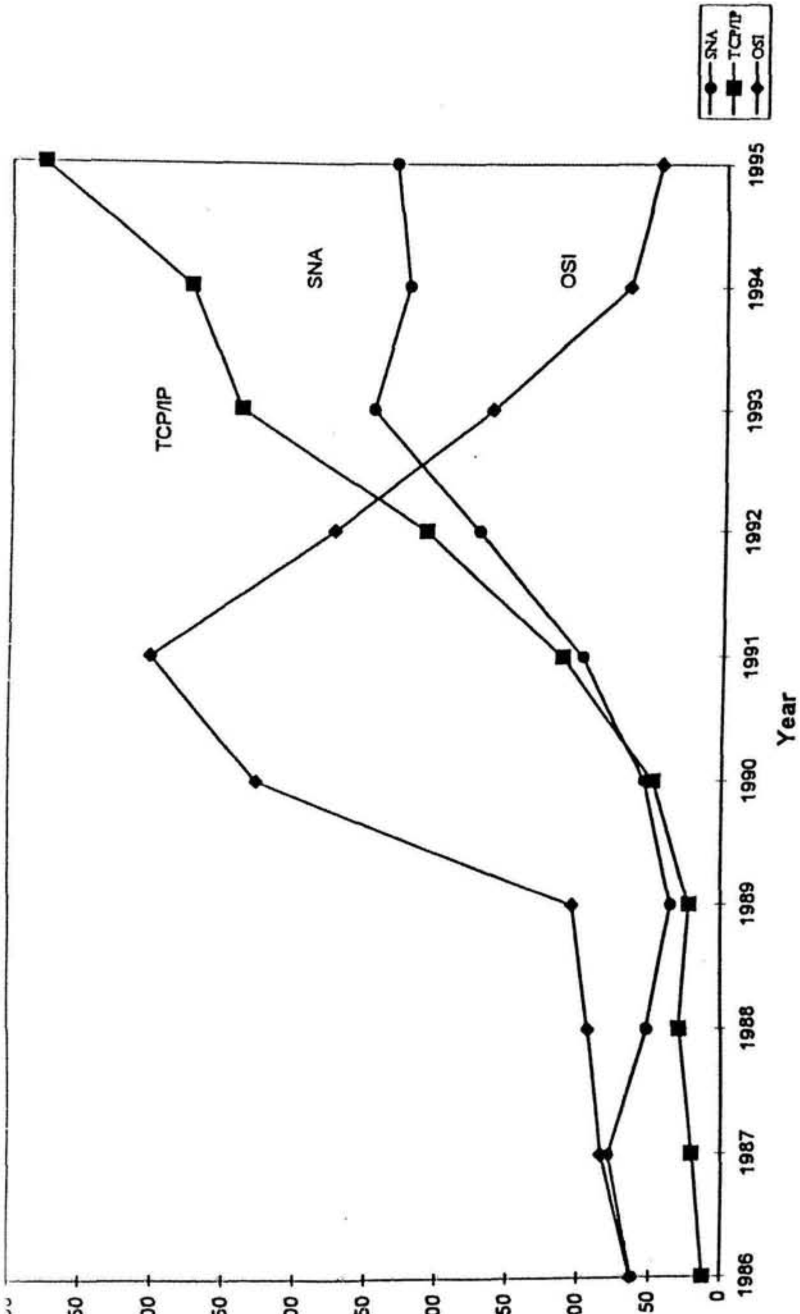

Figure 2. Citation Count of TCP/IP, SNA and OSI in the ABI/Inform Database

From the perspective of our framework (Figure 1), the OSI initiative has remained detached from developments taking place in the technical arena, resulting in the creation of a non-viable institutional platform for both users and vendors. This is represented by Position # 4 in our framework. While SNA has offered functionality as a computer networking protocol from the very beginning, its proprietary nature has constrained user choice and (other) vendor activity along a particular trajectory. This represents Position # 3 in our framework. TCP/IP, in contrast, "just" embeds product market activities associated with the computer networking field. Its availability as a reliable platform has resulted in its adoption by both vendors and users. At the same time, its extensibility as a platform has ensured that new functionalites emerging from the technical environment are rapidly incorporated into the standard. TCP/IP, then, is representative of Position # 1 of our framework.

Platform Availability

The availability of a platform that users can adopt and vendors can innovate upon is key for surmounting the high levels of ambiguity initially associated with a technology and for creating enabling conditions within the technical environment. In the case of computer networking, OSI was promoted through the 1980s as the standard of the future. Once these protocols were finalized, users would have the freedom to implement products manufactured by any vendor in a "mix-and-match" manner and the ability to achieve the kind of connectivity enjoyed by users of the international telephone network.

However, while the OSI community endlessly debated the arcane merits of formal description techniques and protocol implementations, user firms, eager to implement multi-vendor networks, increasingly turned to the alternative that was already available: TCP/IP (see Figure 3). TCP/IP offered much of the networking versatility only promised by OSI protocols.[9] The big attraction of TCP/IP was that it was there, worked reliably and got the job done. The common refrain heard within the user community was "TCP/IP has all the features that we currently require."

The fact that TCP/IP protocol specifications were available in the public domain implied that barriers to entry for vendors wishing to enter this market were relatively low. Besides, all TCP/IP versions could reliably communicate with each other because the Department of Defense maintained strict control over the standard. This centralized control was additional evidence of the reliability of the platform. For both users and vendors, then, the benefits of adopting TCP/IP as their present platform for internetworking computers outweighed the potential costs that would be involved in migrating to OSI in the future.

Even as TCP/IP emerged as the networking protocol of choice, industry consensus was that, over the long haul, most vendors would migrate from this protocol to support OSI standards.[10] A statement made by an industry analyst, David Pass-

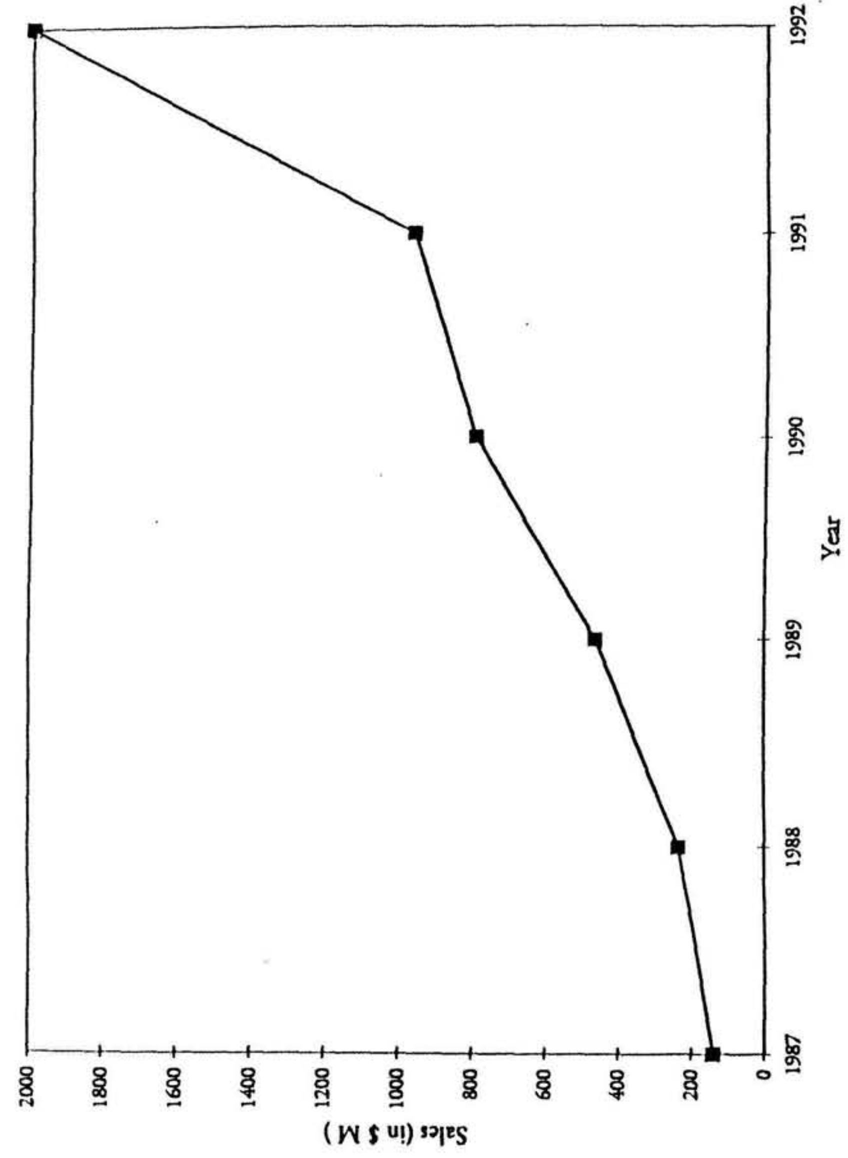

Figure 3. TCP/IP Sales

more, is illustrative—"TCP/IP has at most five years of viability remaining" (*Computer Decisions*, April 22, 1986, p. 51). The assumption was that while the availability of TCP/IP enabled the technical environment in the present, it was dated in terms of its functionalities and would therefore constrain future technical advance.[11]

The story during the 1990s however has turned out differently. While most OSI protocols have been established and products based on these protocols are now available, their impact on the marketplace has been minuscule. A statement by Harvey Freeman, networking consultant, is prophetic in this regard: "Given the rate at which manufacturers are shipping TCP/IP by the time OSI arrives there will be a lot of people who will decide they don't need it. They won't drop a defacto standard just because the "real" standard is here" (*Computerworld*, July 28, 1986, p. 8). Besides, TCP/IP has had many more years of implementation experience behind it, making it a more reliable option. And, according to Dan Lynch, Chairman of InterOp, "There is so much money on the table that people who are selling it (TCP/IP) are evolving it so that it serves additional needs" (*Computerworld*, January 31, 1994, p. 77). Lynch's statement suggests that there have been forces at work that have extended TCP/IP's functionalities over time; a facet that we now explore in greater depth.

Bottom-Up Innovation

From a user viewpoint, standard-setting, in itself, represents a top-down solution to the problem of connecting various computers. Standard-setting, however, is not the only solution available for achieving interoperability. As Howard Anderson of the Yankee Group states, "While users are entranced with the idea of standards, when all is said and done, they go back to what works." (*Computerworld*, December 6, 1993, p. 100). Not willing to wait for standards making organizations to deliver the goods, users have created enterprise-wide networking solutions that involve a mixture of existing proprietary standards and TCP/IP.[12]

Such solutions involve "patchworks" which are technical fixes that overcome problems associated with incompatibility. For instance, transport-layer gateways allow OSI protocols to run on top of TCP/IP. Other solutions include application-layer gateways, dual-protocol stacks and encapsulation.[13] These solutions are available from third-party manufacturers and system integrators, and are equivalent to providing compatibility without committees.

Such mixing and matching comes at a price, either in the form of performance slippage, or in the form of costs that are incurred for acquiring such technologies (David & Bunn, 1988). Nevertheless, there has been an explosive growth of such patchwork solutions. Indeed there are many who share the belief that computer networking will be propelled less by battles between competing standards than by patchwork and translator products between individual protocols.

Besides user needs driving innovation, vendors too have been actively engaging in autonomous innovations. Such innovation is driven by the inherent tension that vendors confront between providing a standardized platform (such as TCP/IP) and the need to differentiate themselves in order to make a profit. As Gerald Tellefsen, a consultant, states "I don't think any vendor will sacrifice profitability to bring standards to the world" (*Computerworld*, June 24, 1991, p. 123). To circumvent this dilemma, vendors have built quirks into their implementations of a standardized protocol or, offer proprietary features to distinguish their product offerings. These advances in networking technologies have subsequently been sponsored by their vendors as protocols to be incorporated into future standards specifications.

Thus, TCP/IP does not appear to have restricted activities in the technical environment of product markets. Specifically, users have employed technical solutions that usually involve TCP/IP to solve their networking problems. Vendors have engaged in autonomous innovations that are subsequently sponsored as standards. For these activities to be sustained, however, it is important for the institutional environment of standards to posses mechanisms by which technical advances can be incorporated into standards over time.

Platform Extensibility

A key mechanism that allows for the rapid extensibility of the TCP/IP platform is its standards-making process. Since 1984, the Internet Architecture Board (IAB) has overseen the development of TCP/IP.[14] TCP/IP evolves through a request-for-change (RFC) process in which enhancements to the protocol are posted to the Internet and then critiqued by users. There is a "winner-take-all" attitude and vendors with competing technologies often conducting implementation "bake offs" to test the mettle of their alternatives, before these are incorporated into standards. TCP/IP, thus, is based on methods known to work prior to standardization activity. The standard setting process has been aptly described as a case of "implement a little, standardize a little, implement a little, standardize a little" (*Government Computer News*, November 22, 1993, p. 22).

Overall, this process brings faster, more reliable improvements to TCP/IP than can be produced by more formal standards-making initiatives.[15] From a user perspective, this has meant that the functionalities provided by TCP/IP have increased over time. For vendors this has implied that, depending upon technical merits, their innovations have been rapidly accommodated in subsequent rounds of standards-setting. Either way, the speed and the incremental nature of the standard-setting process has ensured that use of the TCP/IP platform has not constrained either user functionality or vendor innovation.

Moreover, given the existence of multiple standards, there have been discussions of getting various standards to coexist. This is particularly true of the TCP/IP and OSI initiatives. Many of the features present in the application layer OSI protocols—Message Handling System, File Transfer Access and Management, the Directory and Virtual Terminal—are attempts to improve on their TCP/IP ancestors and are thus functionally more advanced.[16] Rather than migrate to OSI, however, there has been talk of getting TCP/IP and OSI to work together. One option is a Multiprotocol Internet that provides "anything over anything" interoperability in the future. To encourage such a scenario, a white paper put out by the GOSIP Institute in 1992 has recommended that standards bodies such as the IETF and the IGOSS (Industry/Government Open Systems Specifications) collaborate to share the best features of each standard wherever feasible. Such a Multiprotocol Internet represents a "biendian" environment where alternative approaches co-exist with each other.[17]

Summary

The computer networking field then represents a system where the institutional environment of standards (as defined by TCP/IP) "just" embeds the technical environment of product markets. In this field, vendors are actively involved in making technical innovations or in exploiting gaps that exist in the definition of the institutional environment. Users, in their attempts to make computer networking and open systems a reality, are creating their own technological platforms from the products/standards available in the marketplace. Meanwhile, vendors and users jointly are actively attempting to shape the standard-setting process. These standards, in turn shape activities in the technical environment of product markets, albeit in a loosely coupled fashion.

This interplay between the institutional and technical environment allows for rapid advances to be made on both the institutional and technical fronts in a co-evolutionary fashion. Noting this fact, Bill Joy of Sun Microsystems stated (Joy, 1990):

> We have something that economists find truly amazing which I certainly didn't appreciate. We all know that committees take a long time to make standards, and it also appeared, say ten years ago, that the marketplace took a long time, "because everybody just sort of dug in their heels." What we have now is this kind of funny interplay between committees and the marketplace, each trying to outdo the other to set standards, thereby driving the industry forward far more quickly than the other would have done by itself. This is a truly amazing phenomenon.

DISCUSSION

We began this paper by noting the rapid evolution of technological systems in certain fields and the role of the institutional environment in influencing such change. In such contexts, it is important to note that standards themselves need to evolve rapidly in response to developments in the technical arena. Describing the fluid nature of the institutional environment of such systems, Bill Gates, CEO of Microsoft has stated "Standards are generally created in an evolutionary way.

Whether based on the input from customers, industry groups or committees, new standards are continually created and the old ones updated" (*Computerworld*, May 13, 1991, p. 21). Or as a vendor commented, partly in jest, "If you don't like standards now just wait a few years and they'll change" (*Data Communications*, July 1982, p. 101).

The fact that standards themselves are evolving has important implications for the nature of standards competition in such environments. In certain arenas such as network management and high-speed networking, various vendor groups are cooperating to come up with quick and dirty versions of interoperability standards rather than wait for standards bodies to come out with the "official" versions. Thus industry wisdom seems to suggest, "Innovate now; clean up afterward." Often, the defacto standard may be based on an inferior solution that can require additional rework to conform when a dejure standard comes along. However, proprietary products and make-do standards can sometimes pose a sufficient threat to "official" standards.

Another debate relates to the nature of the standards that need to be set. The OSI experience would suggest that implementations tend to diverge unless standards are very tightly written. While in the case of OSI this divergence has proven fatal, other experts take a more tolerant approach to the issue of implementation divergence. As Jim Isaaks of Charles River Data Systems states, "Regardless of how efficiently two systems may one day be able to talk to each other, there are always going to be areas where seamless compatibility just isn't possible. Absolute generic standards can't be done—and if it could, it would stifle the industry." Thus, there may be advantages to leaving some slack in standard-setting. According to Jozef Cornu, acting chief of Alcatel, "If you specify interfaces in a rigid way, you don't leave room for innovation" (*Business Week*, April 10, 1995, p. 106). Achieving a balance between providing a usable standard and yet allowing for the possibility of innovation on the platform would plausibly result in rapid evolution of the overall technological system.

The fact that standards themselves evolve has important implications for understanding the dynamics of this technological field. The institutional environment, as defined by the standards available at any given point in time, does not completely define activities in the technical environment. In this scenario, there are no dominant designs but only dominant solutions that are forged with the availability of patchwork devices that can "glue" disparate systems together allowing users to mix and match components. Besides, an institutional environment specified in such a manner allows for autonomous innovation in the technical arena as firms actively attempt to incorporate their own specific nuances into standardized products. These technological advances are incorporated into existing standards thereby creating an "biendian" technological field. This just embedding relationship between the institutional and the technical environment results in the unfolding of a continual co-evolutionary process.

CONCLUSION

In this paper, we have proposed a framework to view the different types of relationships that exist between the technical and institutional environments of a technological system. This framework, in turn, provides a conceptual scheme to make sense of rapid changes occurring in the computer networking field and allows us to revise and extend our extant views of technological evolution.

These observations are not specific to the networking field alone. Other frontier fields experiencing similar challenges and exhibiting similar dynamics include digital cellular, integrated circuit chips, and data compression and transmission technologies. In each of these fields, the presence of the "just" embedded nature of the technological system ensures that the institutional and technical environments associated with the field co-evolve over time (Van de Ven & Garud, 1994; Garud & Kumaraswamy, 1995).

There are many reasons why it is likely that we will see many new technological fields evolve in this manner. First, it is difficult to foresee ex-ante the functionality that will be required post-hoc, especially in rapidly changing unbounded technological systems, such as those comprising the information superhighway. Second, and equally important, it is doubtful that firms operating in the technical environment will necessarily follow in the same direction dictated by a standard. Each firm is driven to implement its own innovations based on its own realities. Such a situation is all the more likely if standards take considerable time to emerge.

We would like to offer the analogy of a jigsaw puzzle to capture the process of evolution of a "just" embedded technological field. In this analogy, the pieces of the puzzle represent technical solutions that evolve within an overall perimeter that represents institutional boundaries of a technological system. There are two approaches to assembling a jigsaw puzzle. One approach is to understand how all the pieces of the puzzle fit together before attempting to actually put them together. A second approach is to begin assembling the pieces together without a complete appreciation of how the overall puzzle might look.

The computer networking field appears to offer a mid ground between these approaches where users and vendors have begun assembling the pieces within an overall template that is itself changing because of these implementations. Because these pieces are being defined even as they are being put together, they may not fit exactly. However, in preserving dynamic properties of a system, this is not of much concern. Users and vendors have addressed this challenge by using patchwork solutions to fill in the gaps in the puzzle.

How these pieces evolve, and how they are put together, change the vision of the puzzle and its boundary. In turn, the revised boundary directs future evolution of the pieces. This whole process, then, is like a dynamically changing puzzle, wherein the pieces fit together in a loosely coupled manner, and the pieces themselves change with time, constrained to some extent by existing standards, but at the same time, shaping these standards.

Such a perspective is equally applicable to the various types of embeddedness that Zukin and DiMaggio (1990) identified. Embeddedness, for them, refers to the contingent nature of economic action with respect to cognitive, cultural, social and political structures. If we are to create dynamic systems, then, we must think of how we should "just" embed economic actions within these cognitive, cultural, social and political structures. The insights that the computer networking field has to offer are but just a starting point for initiating such an exploration.

APPENDIX

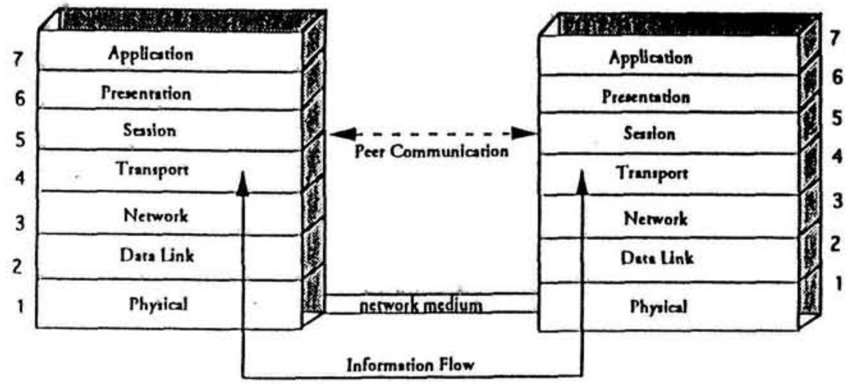

Figure A.1. OSI Reference Model and Network Communication

- The physical layer is concerned with plugs and basic control procedures. It provides basic physical connections on twisted pairs, coaxial cables and fiber optic connections. The physical layer is normally implemented in the hardware.
- The data link layer covers the business of setting up and disconnecting conversations. It also covers error correction. It provides data transparency and data flow control for the connections. The data link layer is sufficiently well-defined that many hardware implementations exist.
- The network level is designed for communications like packet switching in which some systems act only as intermediate nodes. The protocols in this layer cover the routing functions needed to operate such networks.
- The transport layer is concerned with control of data flowing from one system to another outside the scope of the network layer. It provides error-free data transfer between two nonadjacent nodes. In this capacity it provides data sequencing.
- The session layer moves on to the dialog between systems that is essential for the actual exchange of data. It deals with the synchronization and management of a data exchange.

- The presentation layer covers the manner in which data is presented by one system to another.
- The application layer serves as a window onto OSI for application programs. This layer is the highest layer of the standards and represents the point in which applications access open systems.

ACKNOWLEDGMENTS

We thank Joel Baum, Roger Dunbar, Marlene Fiol, Arun Kumaraswamy, "Huggy" Rao, Brian Uzzi and the participants of the "Embeddedness of Strategy" Mini-conference at the University of Michigan for their valuable insights.

NOTES

1. This is analogous to Granovetter's (1985) notion of embeddedness. Granovetter states: "Actors do not behave or decide as atoms outside a social context, nor do they adhere slavishly to a script written for them by the particular intersection of social categories that they happen to occupy. Their attempts at purposive action are instead embedded in concrete, ongoing systems of social relations" (Granovetter, 1985, p. 487). This view of embeddedness threads its way between the oversocialized and undersocialized notions of economic actions. Work by Burt (1982) and Uzzi (forthcoming) also focus on such a notion of embeddedness. Zukin and DiMaggio (1990) suggest that embeddedness may not be just structural in nature, but may also have cognitive, cultural and political components.

2. In the case of computers, standards would have to specify "how programs and commands will work and data will move around the system—the communication protocols that hardware components must follow, the rules for exchanging data between application software packages and the operating system, the allowable font descriptions that can be communicated to a printer, and so forth" (Ferguson & Morris, 1993, p. 120).

3. The framework employed is derived from semiotic analysis (Griemas, 1966; Eco, 1979; Fiol, 1989). The terms in the semiotic square are grouped in pairs into six systematic definitions (Griemas, 1966): (1) two deixes, (left and right vertical relationships marked as positions 1 & 2) related by implication, (2) two axes, (upper and lower horizontal relationships marked as positions 3 & 4), related by contradiction, and (3) two schemas (the diagonals), each formed by the relation of contradiction, with the two schemas themselves related as contraries.

4. The term TCP/IP refers either specifically to the Transmission control protocol (TCP) and Internet protocol (IP) or generally to the whole set of protocols that have been developed by the Internet community to operate in conjunction with TCP and IP in the Internet and in individual enterprise-specific internets. We employ the latter definition here.

5. The global Internet, whose size is currently estimated at over 1.5 million computers and 5 million users, is based on this set of computer networking protocols.

6. DEC followed shortly thereafter with its own set of proprietary networking protocols, Decnet.

7. SNA represented the quintessential proprietary network, enabling IBM to keep customers in their fold by dictating how changes to their networking protocols would be made. In addition, due to its clout, IBM had a reputation for selective obstructionism when involved in industry wide standards-making.

8. The layers and their functions were chosen based on natural subtask divisions. Each layer communicates with its peer in the other computer, but does so by sending messages through the layers in its own computer.

9. TCP/IP enabled various vendors' products to interconnect with minimal problems if one stuck to the basic services: virtual terminal (TELNET), electronic mail and file transfer (FTP).

10. This issue is linked to the functionalities provided by the two standards. We can simplify the discussion by making a distinction between the "lower layers" and the "upper layers." The lower layers cover basic inter-program communications over a network or over a connected set of networks—that is, internetworks. The upper layers provide the functionality that has application semantics. OSI and TCP/IP are quite similar at the lower levels. While there are concerns about TCP/IP's weakness in terms of window size and address space, OSI's lower layers are criticized for architectural complexity. However, while TCP/IP's application services (i.e., higher layers) do mostly simple things well, the OSI applications, especially E-mail and directory services, attempt to provide much more ambitious services and promise extremely rich capabilities, such as the exchange of multimedia documents. In this regard, it has been suggested that OSI is the "better" model of distributed applications and that TCP/IP is the "better" model for the networks that support their communication.

11. Interestingly enough, strong support for OSI protocols came from the Department of Defense (DoD) who in 1988 indicated that they would adopt these as they became available, with TCP/IP being used in the interim. Likewise, the Federal Government, through Government Open Systems Interconnect Profile (GOSIP) mandated the purchase of networking products based on OSI protocols by all government agencies. And two large user-based purchase specifications—MAP (Manufacturing Automation Protocol), initiated by General Motors and TOP (Technical and Office Protocol), started by Boeing—also recommended the use of OSI-based products as they became available.

12. In such scenarios, however, users appear to have resigned themselves to the extra work required of them to ensure enterprise-wide interoperability. As Patricia Keefe states: "In their rush to get out from under the tyranny of single-vendor solutions, users are discovering that mixed standards and multivendor environments have created a Pandora's box of network management nightmares" (*Computerworld*, December 26/January 2, 1988, p. 25).

13. Besides, many software vendors have taken it upon themselves to provide a uniform layer (API) spanning a variety of networking protocols—another technical solution to circumvent the absence of a well-defined institutional environment

14. Working groups organized under the auspices of the IETF (Internet Engineering Task Force) are responsible for actual standard-setting.

15. In contrast, the rancourous nature of the standard-setting process within the OSI community prompted Carl Cargill to comment, "The ability to participate in (setting) external standards is less a function of technical ability than it is of endurance" (*Datamation*, September 1, 1989, p. 64). An issue that plagued the OSI initiative from the start is that whenever the committee members failed to agree, they accomodated the interests of various parties. Rather than make the hard choices—that is, define one manadatory OSI stack—they continued to permit many to coexist, this in turn jeopardizing the interoperability of different implementations.

To ensure compatibility, in many cases, profile groups were established to whittle down the number of implementation possibilities—this being equivalent to a second standardization process. Even after official standards were established, it was often the case that networking products from two different vendors simply did not work together. Thus there was the need for organizations to provide conformance testing and interoperability testing. However, it is only recently that OSI conformance and interoperability tests have become available from an independent source.

16. Many of the people who developed TCP/IP have now become involved with the development of OSI protocols. As one observer remarked , "When you do it a second time, you learn a few things. OSI is richer in function, has more features and deals with problems that are not dealt with in TCP/IP."

17. A recent *Business Week* (April 10, 1995) article suggests that the traditional battles between incompatible systems is similar to the fight between the Big-Endians and Little-Endians (kingdoms whose only difference is in where to crack open a hard-boiled egg) described in Swift's Gulliver's Travels. According to this article, new technologies are beginning to close such rifts. The article suggests the notion of biendian to describe the coexistence of incompatible systems.

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