A model of Internet standards adoption: the case of IPv6

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Abstract. *The Internet presents a unique environment in which to study adoption. This is because of its composition of autonomous entities that are otherwise strongly interrelated. Our model of Internet standards adoption (ISA) combines diffusion of innovation and economics of adoption literature to present an integrative model. This model proposes that the adoption of Internet-based standards is dependent upon two dimensions: the usefulness of the features to the potential adopter, and the conduciveness of the environment to adoption of the standard. This model accounts for not only the traditional dichotomous view of adoption, but also includes the notion of 'partial adoption', where both old and new standards can coexist for extended periods of time. As a demonstration, we apply the ISA model to the next generation Internet protocol Internet Protocol version 6 (IPv6). Despite its ostensible superiority, IPv6 has not been widely adopted. In this paper we discuss the reasons why this might be the case. Our analysis also draws wider conclusions about the adoption of Internet standards: in particular, the importance of transitional technologies between the old and new standards and the need for co-ordinated government polices which encourage adoption. Our analysis also indicates that geopolitical boundaries may have a considerable impact on the adoption of Internet standards.*

Keywords: adoption, diffusion of innovations, Internet standards, Internet, IPv6, partial adoption

INTRODUCTION

The Internet, often described as a 'network of networks', is a loosely organized system of autonomous yet interconnected networks that support host-to-host communication (Bradner, 1996). Its success is due, in part, to the voluntary adherence to open protocols and procedures which are periodically updated in the Request for Comments (RFC)[1] titled 'Internet Official Protocol Standards' (Reynolds *et al*., 2001), last published in November 2002. Despite the Internet's inherently distributed nature, its participants are also strongly interrelated (Bradner, 1996). These participants share common resources (e.g. Network Access Points to a central backbone) and use common protocols [such as Transmission Control Protocol (TCP), Internet Protocol version 4 (IPv4), and File Transfer Protocol (FTP)]. The tension created by these autonomous entities that are also strongly interrelated provides a unique context against which to examine the diffusion of Internet standards. Fichman & Kemerer (1994) suggest that 'no single strongly predictive theory of innovation adoption and diffusion is likely to emerge' (p. 23), and researchers should focus on specific innovations and contexts. Adopting this perspective, in this paper we focus on the diffusion of standards in the context of the Internet. Moreover, there is little research on the adoption of Information Technology standards in general (Lyytinen *et al*., 1998), and more specifically little research on the adoption of Internet standards.

An example of one such standard is the next generation of the Internet protocol, Internet Protocol version 6 (IPv6). Although technically superior to IPv4, and despite its announcement as a proposed standard in 1998, IPv6 has yet to achieve widespread adoption. In fact, an informal poll of 50 Internet service providers (ISPs)[2] found that none of them had implemented the new protocol. An ISP's decision to implement IPv6 exemplifies the tension between the decentralized nature of the Internet and the need for consensus. Each ISP can decide for itself based on its strategic intent if it should adopt IPv6. The decision, however, must also take into account the ISP's interoperability with other Internet-connected parties. Thus, the adoption decision has to be made cognizant of decisions made by Network Access Points, other ISPs, and equipment providers.

The goal of this paper is to analyse the adoption of Internet standards and propose a framework that can be used by researchers and practitioners to understand how the adoption of Internet standards differs from the adoption of other technological innovations. By examining the specific case of IPv6, we conclude that government involvement and sponsorship can have a major impact on the diffusion of Internet standards. We also conclude that disparities in resource allocation can lead to a crisis that can operate as a catalyst to expedite implementations in various regions.

As a first step, we examined the traditional theory on diffusion and found that it is insufficient to explain the adoption pattern of Internet standards. The diffusion of innovation (DOI) approach, put forth by Rogers (1962; 1983), emphasizes the impact of the features of an innovation and the characteristics of the adopting individual, group, or organization. This stream of

[1]RFCs (Requests for Comments) are the official publication channel for Internet standards documents and other topics of interest to the Internet community. In addition to publishing standards, RFCs cover a wide range of topics, from early discussion of ideas to status memos about the Internet. These documents may be obtained from several web sites, including the site of the IETF at http://www.ietf.org.

[2]An informal poll was conducted by the authors in November 2000. The first 50 ISPs (out of 416 total) listed at http://www.ispfinder.com in the 215 area code (metropolitan Philadelphia) were selected. The web site lists the ISPs in alphabetical order. Each ISP was contacted and asked if they currently supported IPv6.

research primarily examines the factors that influence the individual organization's adoption decision. Alternatively, the economic view of diffusion (Farrell & Saloner, 1985, 1987) primarily looks at the economic benefit to a potential adopter. This perspective on diffusion theory views the adoption decision solely as a function of the decisions of others (the community effect). To overcome this deficiency in the literature, we draw on the work of Fichman & Kemerer (1993) to present an integrative model of Internet standards adoption (ISA) that combines organizational adoption factors and community adoption factors. We extend this work to present a model that re-examines those two dimensions in the context of adoption of a new Internet standard. Where Fichman and Kemerer analysed the adoptability of multiple software process innovations, our investigation focuses on the adopting organization as the unit of analysis, and is based on the two dimensions of our model – usefulness of features and conduciveness of the environment. We apply these two dimensions to explain the influence of the independent adoption decisions of each player (DOI), and the influence of community effects (economics).

In addition to addressing standards adoption, this paper also addresses one of the criticisms of diffusion research (Bayer & Malone, 1989) – the view of adoption as a dichotomous outcome (either the innovation is adopted or it is not) – by illustrating the modalities of *partial adoption*. Our model uses the two dimensions described to suggest four potential 'modes' of adoption:

1 Non-adoption of the standard;
2 Adoption through replacement;
3 Adoption through coexistence; and
4 Full adoption.

Two of these modes represent the traditional dichotomous notion of adoption – either full adoption of the standard or non-adoption of the standard. In addition to these, we propose two modes that describe *partial adoption* (Figure 1). We show how a standard can potentially achieve diffusion by 'adoption through replacement', where the new standard is implemented in place of the old standard although its new features are not fully utilized. Alternatively, 'adoption through coexistence' can occur, where both standards exist within the same organization. In this case, adopters will likely take advantage of the standard's new features to serve niche markets.

We use the adoption of IPv6 to demonstrate the application of our two-dimension model. Using the model, we can classify the potential adopter community of ISPs into one of four modes of adoption at any point in time, depending on their current operating environment and the usefulness of the features (UF) to the ISP.

In the next section, we present the theoretical foundation for the model. Next, we describe our model of ISA. We then show that four distinct modes of standards adoption are implied by our model, and how those four cases suggest two distinct paths to full adoption. We use the ISA model to explain potential adoption patterns of the Internet protocol IPv6, and then demonstrate how our model can be used to explain the adoption pattern of other Internet standards. We conclude with recommendations regarding how to encourage the adoption of Internet-based standards, and suggest future research directions.

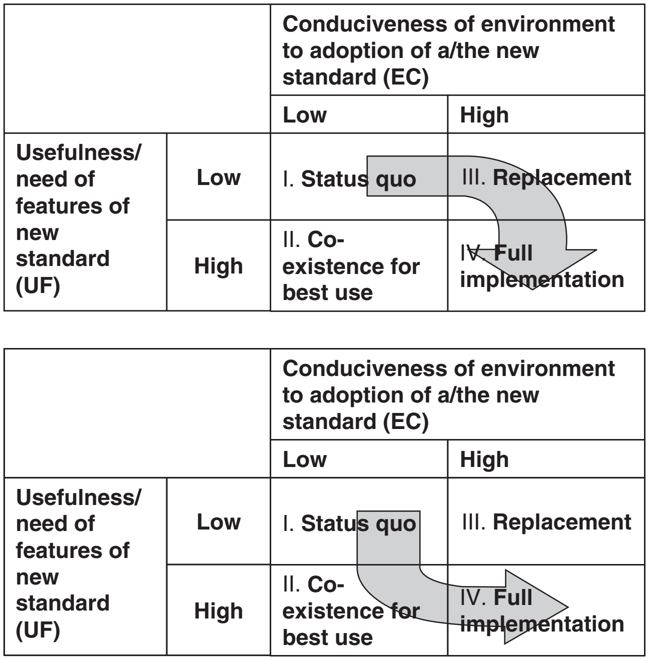

Figure 1. Modes of adoption of Internet standards.

DOMINANT THEORETICAL PERSPECTIVES ON DIFFUSION

Research on diffusion is divided into two main streams. *Diffusion of innovation* literature attempts to understand and explain how innovations are spread across a population of potential adopters over time (Rogers 1962; 1983) and its application within an organizational context (Tornatzky & Klein, 1982; Kwon & Zmud, 1987; Van de Ven, 1993a). The basic focus of this line of investigation is the attributes of the innovation and their value to the organization. The *economic perspective* of innovation adoption focuses on an innovation's inherent economic value to potential adopters (e.g. Rosenburg, 1982; Katz & Shapiro, 1986; Arthur, 1996). This value will depend on the size of both the existing and the potential network of adopters. The following sections elaborate on current diffusion literature.

Diffusion of innovation literature

Classical diffusion theory, developed in the context of individual adopters, considers diffusion of an innovation as a social process of communication, where potential adopters become aware of the innovation and consider its adoption (Rogers 1962; 1983). A dominant theme in the traditional DOI research has been to identify and examine attributes of innovations and their influence on the decision to adopt. Rogers (1962; 1983) identified five such generic innovation characteristics: (1) *relative advantage*, (2) *compatibility,* (3) *complexity* (4) *trialability*, and

(5) *observability*. Tornatzky & Klein (1982) found only relative advantage and complexity to be consistently related to adoption. Other researchers proposed additional attributes that in most cases were mapped to one of these five attributes (Fichman & Kemerer, 1993). Generally, most DOI studies either use or build upon the five basic attributes identified by Rogers (1962; 1983).

Although Rogers' (1962; 1983) meta-analysis was based on studies of adoption by individuals, subsequent research applied the same five attributes to adoption decisions in organizational contexts (e.g. Eveland & Tornatzky, 1990; Van de Ven, 1993a). As in the case of individual adoption decisions, the attributes of an innovation influence organizational adoption decisions (Fichman & Kemerer, 1993) and the innovation's subsequent use in organizations (Eveland & Tornatzky, 1990).

Economic approach to the diffusion of innovations

Fichman & Kemerer (1993) characterize the economic perspective as one that looks at the adoptability of an innovation by a community. The economic approach to adoption is based on the premise that the benefit of adopting an innovation is a function of the number of current and potential adopters, also referred to as network externalities (Farrell & Saloner, 1985; Katz & Shapiro, 1986; Arthur, 1996). The presence of positive network externalities has been associated with several community level factors. They include economies of scale (Arrow, 1962), knowledge from increased use (Rosenburg, 1982), and the extent of the related technological infrastructure (Arthur, 1988). Presence of a large installed base of existing technology introduces drag on the adoption of a new innovation (Farrell & Saloner, 1986), where potential adopters may be reluctant to adopt even if the innovation is superior. It has also been argued that adoption inefficiencies can result from a lack of communication among adopters (Farrell & Saloner, 1985; Nilakanta & Scamell, 1990). Katz & Shapiro (1986) suggest that the existence of sponsorship, where an individual, organization, or government may provide monetary and non-monetary incentives has a positive effect on adoption of an innovation. Van de Ven (1993b) suggests that the process for setting standards is influenced by social and political dynamics, and that governmental regulation facilitates the emergence of new technologies. Another factor discussed in the literature is the availability and allocation of resources that may be either evenly distributed throughout a community, or disproportionately concentrated among a few (Kwon & Zmud, 1987). Table 1 summarizes the two streams of diffusion literature reviewed in this section.

Diffusion in the context of the Internet

Fichman & Kemerer (1993) proposed that each stream of research individually is not enough to explain the adoption of an innovation. However, their work focused on the adoption of process innovations. In that context, the need for a community of adopters is important but not compulsory. For a given organization, the decision to adopt a certain type of database, a CASE tool, or a programming language can be achieved with little regard to the decisions made by other stakeholders (i.e. many organizations develop proprietary software tailored to their specific requirements).

Table 1. Summary of DOI and economic adoption literature

Factor	Description
Diffusion of innovation (feature-oriented)	
Relative advantage	Innovation offers clear advantages over current practices or products. (Rogers, 1962; 1983; Tornatzky & Klein, 1982)
Compatibility	Innovation is compatible with existing practices and capabilities. (Rogers, 1962; 1983; Tornatzky & Klein, 1982)
Complexity	The level of complexity in understanding and use of innovation. (Rogers, 1962; 1983)
Trialability	The ability to try an innovation with minimal commitment of resources. (Rogers, 1962; 1983; Fichman & Kemerer, 1993)
Observability	The ability to observe and communicate the benefits of adopting the innovation. (Rogers, 1962; 1983; Fichman & Kemerer, 1993)
Economic perspective (environment-oriented)	
Factor	Description
Network externalities	Adoption of innovation depends upon the number of current and future adopters in the community. (Farrell & Saloner, 1985; Katz & Shapiro, 1986)
Related technologies	The extent to which a system of compatible products is available. (Arthur, 1988)
Installed base/drag/inertia	Installed base of existing products introduces a drag on adoption of innovation. (Farrell & aloner, 1986)
Irreversible investments, sunk cost	Investments incurred by adoption are irreversible. (Farrell & Saloner, 1987; Keil *et al*., 1995)
Communications channels and general industry knowledge	Existence of communication channels for the dissemination of knowledge about the innovation. Rosenburg, 1982; Farrell & Saloner, 1985; 1987; Kwon & Zmud, 1987; Arthur, 1988; Nilakanta & Scamell, 1990)
Sponsorship	The presence of an entity that promotes adoption with monetary or non-monetary incentives. (Katz & Shapiro, 1986; Van de Ven, 1993b)
Resources (availability and allocation)	Availability and distribution of resources in the community. (Kwon & Zmud, 1987)

While Fichman and Kemerer used the dimensions of organizational and community adoptability to assess the overall attractiveness of several different innovations, we use this framework to assess the adoptability of a single innovation across multiple firms. This is an important perspective when viewing adoption within the context of the Internet, because the required interoperability among the various stakeholders implies that decisions cannot be made in isolation. For example, an organization cannot develop and adopt a proprietary email protocol for external communication because it will not be compatible with the protocols used by other firms. In the remainder of this section, we illustrate the unique characteristics of the Internet and the need for a more integrative model.

Diffusion of standards

Standards compete for adopters in a way similar to innovations and new technologies (Arthur, 1988). Therefore, it is possible to apply DOI theories to study the diffusion of standards. For example, the adoption of a home video recording standard in the early 1980s can be analysed using factors from the DOI literature. The consumer electronic industry introduced two competing standards for video recorders, Beta (developed by Sony) and VHS (developed by JVC). VHS benefited from the existence of related and complementary technologies and the network externalities provided by a population of affiliated vendors (Cusumano *et al*., 1997). As a result, VHS was adopted as a universal standard despite Beta's technical superiority.

As mentioned previously, one of the main criticisms of diffusion research is that adoption has been modelled primarily as a dichotomous outcome – adoption vs. non-adoption (Bayer & Malone, 1989). The 'adoption vs. non-adoption' approach does not fully address two potential scenarios for the adoption of standards across the Internet:

1 Because of the autonomy of participating firms, only some firms may elect to adopt the standard; and
2 Many Internet standards consist of multiple features. An organization might adopt a standard to take advantage of network externalities, but elect to use only some of the features based on their specific needs.

These differences occur in particular with Internet standards because of the existence of two contradictory forces: the decentralized nature of the Internet vs. the need for high interoperability. This tension is apparent in the governance structures of the Internet, which have been put into place to develop and disseminate standards in order to guide the Internet's development and support its required interoperability. However, these organizations are loosely organized democratic bodies composed of both commercial and non-commercial stakeholders (exemplifying the decentralized nature of the Internet). The earliest structure was the Internet Configuration Control Board (Leiner *et al*., 1997). As the Internet grew, additional structures were introduced [such as the Internet Architecture Board (IAB) and Internet Engineering Task Force (IETF)]. Additional entities such as the Internet Society and the World Wide Web Consortium (W3C) were created in the 1990s (Leiner *et al*., 1997). Unlike most environments that require high levels of interoperability and have some central governance that dictates baseline standards (e.g. the International Telecommunications Union (ITU) establishes telephone standards), entities such as the IETF and W3C can recommend a standard but cannot mandate nor enforce it. Also, these organizations do not provide monetary or regulatory incentives to adopt new standards.

The combination of autonomous adoption because of the lack of central governance and the demand for interoperability is unique to the Internet. Leiner *et al*. (1997) assert that for the Internet's continued success, a social structure that recognizes the diversity of its stakeholders must continue to exist. They acknowledge the importance of not only the emergence of new technology, but also the ability 'to set a direction and march collectively into the future' (p. 108), even in the absence of central governance.

While the DOI perspective focuses solely on the characteristics of the innovation and the adopters (taking into account the Internet's decentralized structure), it only addresses adoption decisions of individual firms. The economic perspective examines the community effects (taking into account the Internet's inherent interrelatedness), explaining a firm's decision to adopt by virtue of its being a member of a community of potential adopters. A model which can explain standards adoption in this context must take these two aspects into account.

A MODEL OF INTERNET STANDARDS ADOPTION

The proposed model of ISA represents the view that adoption is a function of both the utility of the standard's characteristics (the individual perspective), and the environment in which the adopter operates (the community perspective).

We can group the factors influencing adoption from both the DOI and economic perspectives along two dimensions: feature-oriented factors, which determine *usefulness of the features* and environmental-oriented factors, which determine *environmental conduciveness (EC)* of the standard. Both dimensions are shown in our proposed model (see Figure 2) and are described below.

Usefulness of the features of the new standard (UF)

Fichman & Kemerer's (1993) unit of analysis is the innovation itself, and they assume that the attributes of a technology are valued equally by all firms. In contrast, our unit of analysis is the

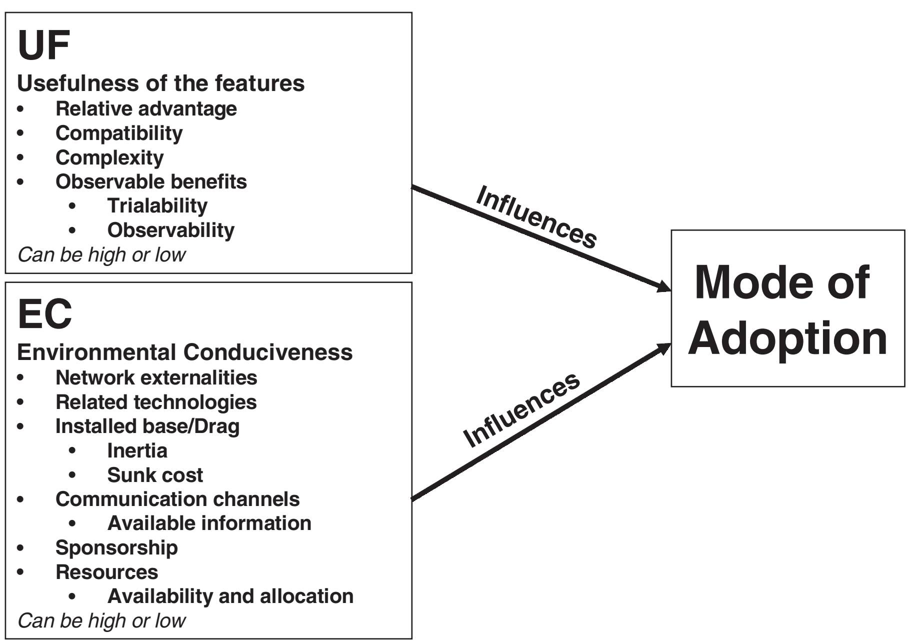

Figure 2. Internet standards adoption (ISA) model.

adopting organization. This is based on the premise that each organization values an innovation and its attributes differently. In the following discussion, we refer to the organization's perceptions of the utility of the features of the standard to the adopting organization.

Standards are likely to consist of a set of features that may have varying levels of attractiveness and may be adopted to varying extents by organizations. Different organizations may choose to implement different features of the standard, particularly when specific features are independent of each other and can be easily unbundled. DOI literature identifies five attributes of innovations (Rogers 1962; 1983), as described in Table 1. One attribute that has been consistently related to adoption is the *relative advantage* offered by the features of a new standard over existing standards. These features could generate new markets, products, and services creating competitive advantage opportunities for early adopters.

With *backwards compatibility,* the ability of the new standard to work with existing technologies or infrastructure, a new standard can be implemented as the old standard is being phased out. This has the potential for offering a competitive advantage to first movers who can identify potential niche markets for exploitation by upgrading to the new standard. Compatibility is important in the Internet environment because of the need for interoperability. Because all potential adopters may not upgrade at the same time, features that are compatible with technologies based on existing standards are more likely to be adopted. For example, the Extensible Markup Language (XML) is compatible with existing set of X12 Electronic Data Interchange (EDI) standards.[3] The implementation of an XML-based business-to-business infrastructure can easily be built upon an existing EDI infrastructure, increasing the viability of XML adoption.

Increased *complexity* of the standard's features increases the effort required to implement it, and therefore reduces the number of potential adopters. Complex features are less likely to proliferate, especially if their benefits over the existing standard are not clear. In an Internet environment, interoperability considerations may compel an organization to adopt a standard, but a high level of complexity may result in a minimal number of the standard's features actually being used, leading to partial adoption.

The ability to verify and quantify the benefits of the new standard or its *trialability* is also likely to influence the attractiveness of a new standard. Features that can be assessed without commitment and are easy to quantify will have an increased perceived value, reducing the perceived risk of adoption. This is particularly important in the context of the Internet because due to the lack of central governance there is no central entity that is responsible for the creation of testbeds and trials for the new standard. Such trials have to be funded by private industry and depend on available research and development funds. *Observability* refers to organizations' ability to observe benefits from the adoption of a given feature or a set of features. Observable benefits in the Internet environment are particularly relevant as they can reduce the perceived risk associated with adopting a new standard. Because there is no central governance structure sponsoring or mandating adoption, it is important to be able to observe the benefits from the adoption of a new standard and have a quantifiable advantage to the implementation of the new

[3]For more information, see http://www.x12.org.

standard. These advantages can come through the implementation of related technologies, or via other competitive advantages that the standard's features can provide.

Environmental conduciveness to Internet standards

As stated previously, Fichman & Kemerer (1993) applied their framework to the adoption of software process innovations within an organization. This framework cannot be directly applied to the context of ISA because it does not take into account the tension between the independent decision making and required interoperability evident in the context of the Internet. This high interoperability makes the influence of the community over the adoption decision especially important. This dimension, which we have labelled 'EC', is characterized by environmental factors that favour an organization's adoption of a standard by creating an environment that is amenable to adoption.

Research based on the economics of standards approach notes that a primary factor in creating such an environment is the presence of *positive network externalities* (Katz & Shapiro, 1986). This refers to the benefits created through the adoption of the new standard by other organizations in the community. Positive network externalities provide support to expectations of widespread adoption of a standard. Typically, the result is a reduction in cost because of economies of scale and synergies created through increased opportunities of interactions among adopters. As more organizations adopt the standard, barriers to adoption for others in the community are lowered (Rosenburg, 1982; Arthur, 1988). Conversely, the inability to create network externalities can impede the adoption of a standard even when it is superior to rival standards (Cusumano *et al*., 1997). Network externalities are important when examining the adoption of Internet standards because of the need for interoperability. It is essential that a substantial number of organizations adopt the new standard so that the resulting positive network externalities can reduce the risk of adoption created by the lack of central governance.

The existence of *related technologies* (Arthur, 1988) creates a large base of products compatible with a new standard. Complimentary or related technologies (Cusumano *et al*., 1997) increase the standard's inherent value, encouraging its adoption. These 'complementary technologies' could be applications that use the standard. The development of related technologies can also increase network externalities as more vendors have a stake in the new standard.

The state of the current infrastructure characterized by its *installed base*, the resulting *inertia*, and *sunk cost*s in existing technology can play an important role in determining the attractiveness of the environment for adoption (Farrell & Saloner, 1986; 1987). A well-established standard with a large installed base can create high drag and inertia, making the environment less attractive thereby deterring organizations from adopting a new standard. This can be because of high levels of familiarity with the existing standard or the existence of well-developed skill sets. Potential adopters are less likely to switch when a legacy standard is relatively inexpensive to maintain or when the perceived risk in implementing a new standard is high. Similarly, perceptions of high sunk cost can lead to lower proliferation of the new standard, as the idea of 'throwing out' existing investment creates a reluctance to abandon the current standard. A large installed base can have a negative impact on the adoption of new standards even when the existing standard is inferior. For example, Gould (1997) states that the main reason for the survival of the QWERTY typing system, despite its inferiority, is its enormous installed base. Such conditions result in higher costs to convert to the new standard, which in turn is likely to limit its attractiveness to potential adopters. Environments where the new standard can build upon existing components of the current standard, and where these components can be replaced by attrition rather than being disposed of (resulting in a lower sunk cost), are more conducive to adoption.

These factors are particularly relevant within the context of the adoption of Internet standards. The effects of the large existing installed base and consequent inertia (as well as the resulting costs to convert and perceptions of sunk cost) are accentuated by the interoperability requirements imposed by this environment. An organization's decision to upgrade to the new standard will also depend on the existing infrastructure of other related companies, such as competitors, customers, and vendors. With the absence of central governance, a number of competing standards may coexist despite the negative effect this may have on interoperability.

Available *communication channels* facilitate accessibility to information by organizations regarding the new standard (Rosenburg, 1982; Nilakanta & Scamell, 1990). The voluntary flow of information between existing and potential adopters is important for creating positive expectations, and the general availability of information about the standard has a positive impact on the diffusion of an innovation (Nilakanta & Scamell, 1990). However, the amount of information available regarding a standard can vary between environments (Kwon & Zmud, 1987). The voluntary dissemination of knowledge among potential adopters is especially important in the context of the Internet because of the lack of a strong central governing body that can be used as a primary and definitive source of information beyond initial specifications.

The level of *sponsorship* (governmental or private support of the new standard) also plays an important role in determining the environmental context for new standards. Morison (1997) concluded that it is difficult for a community to adopt a new standard without the intervention of an external agent in a position of power. In environments with strong government or private support, the ability for a new standard to proliferate is increased because sponsors can take the role of the central authority that the Internet currently lacks. Government sponsorship, for example, can (1) mandate the implementation of the new standard in a certain region, (2) defray some of the cost to upgrade through tax credits or training programs, or (3) increase network externalities through awareness programs, collaboration, and consortia which increase implementation synchronization. Private support can (1) increase network externalities through the creation of consortia, (2) introduce an artificial crisis by stopping the support of technologies based on the old standard (by mandating a 'cutover' date), (3) provide monetary incentives to early adopters, and (4) develop transitional technologies.

The proposed framework

Based on the UF and EC dimensions, we propose a two-by-two framework that describes distinct 'modes' of ISA (see Figure 3). Each dimension is separated into two levels: low and high. The result is four quadrants, each representing a mode of adoption. The first is labelled 'status

		Conduciveness of environment to adoption of a/the new standard (EC)	
		Low	**High**
Usefulness/ need of features of new standard (UF)	**Low**	I. **Status quo** *Stay where you are*	III. **Replacement** *Implement but with no new features – use like the old technology*
	High	II. **Co-existence for best use (*niche*)** *Implement with some but not all features, and support both in the transition*	IV. **Full implementation** *Implement new standard with all of the features*

Figure 3. Modes of adoption based on ISA model.

quo', where both EC and UF is low. An organization operating in the first quadrant ('status quo') is unlikely to adopt the new standard.

The second quadrant is labelled 'coexistence for best use', and describes a situation where EC is low but the usefulness of some features is high. In this case, an organization might implement the features of the new standard for a particular group while maintaining the existing standard for other markets. This strategy is used to maintain interoperability with other related organizations in its environment. In the third quadrant, labelled 'replacement', the EC is high but the UF is low. In this case, the new standard is implemented, but there is minimal use of its new features and capabilities. Thus, the new standard is used in much the same way as its predecessor. One instance in which replacement may occur is a forced upgrade. When a vendor stops supporting a technology or a new standard becomes the default choice, companies will be forced to adopt the new standard whether or not they intend to use its features. A complete adoption of the new standard and its capabilities (called 'full implementation') occurs in the fourth case, where both EC and feature usefulness are high.

In summary, the model (shown in Figure 2) and the resulting framework (shown in Figure 3) recognize that individual organizations may operate in an environment whose conduciveness to the adoption of the new standard is either high or low, and the standard's features for that organization may have high or low utility. Thus, the decision to adopt and the mode of adoption depend on both of these dimensions as they facilitate the realization of an organization's strategic objectives within a given environment. We propose that potential adopters will be placed into one of these four quadrants. If both dimensions are low, the standard will not be adopted by the organization. If both dimensions are high, full adoption will occur. In the remaining two cases, where one dimension is high and the other is low, partial adoption will occur. This mode of adoption will be driven either by the features of the standard (i.e. only selected features of the standards are adopted) or by the environment in which the organization operates (i.e. only certain organizations adopt the standard).

Early stages of adoption of a new standard where a legacy standard exists would necessarily begin in ‘status quo’ (quadrant 1). Firms choosing not to adopt would remain in this quadrant. For those who choose to adopt, there is a movement towards eventual full implementation (quadrant 4). The path from quadrant 1 to quadrant 4, whether it is via ‘replacement’ or ‘coexistence’, depends on the characteristics of the environment in which the organization operates and on the value placed on the features by each organization. We discuss each of these paths next.

PATHS TO STANDARDS ADOPTION IMPLIED BY THE ISA FRAMEWORK

Adoption through replacement

The first path can be characterized as ‘adoption through replacement’ (Figure 4), where organizations replace the old standard with the new one while not taking advantage of its new fea-

		Conduciveness of environment to adoption of a/the new standard (EC)	
		Low	**High**
Usefulness/ need of features of new standard (UF)	**Low**	I. **Status quo** *Stay where you are*	III. **Replacement** *Implement but with no new features – use like the old technology*
	High	II. **Co-existence for best use** *Implement with some but not all features, and support both in the transition*	IV. **Full implementation** *Implement new standard with all of the features*

Figure 4. Adoption through replacement.

tures. This is done for two reasons: to maintain interoperability with other Internet companies and to take advantage of an incentive that makes the environment conducive to the replacement of the older standard.

For example, RealNetworks' RealOne media player will play media files created with older versions of their proprietary format. In addition, they distribute decoding software (codecs) which allows their media player to play many older digital audio and video formats from other vendors. The resulting compatibility enables potential adopters to implement RealNetwork's newest media player without necessarily using their newest media format (features). Over time, the organization may implement additional aspects of the new standard based on need until they achieve full implementation.

It is possible that organizations in environments where the standard is novel, and a comparable legacy standard does not exist, may move to full implementation via a 'replacement-like' path. In this case there is no previously implemented standard with which to coexist. Therefore, the EC is high because there is no drag, inertia, or sunk cost. Firms in this case implement a new standard by default and do not see a strategic need to implement its advanced features (low relative advantage). For these potential adopters, the UF is initially low and as the utility of the features becomes evident, there is a move towards full implementation.

Adoption through co-existence

A second path can be called 'adoption through coexistence' (Figure 5), where organizations phase-in features of the new standard needed to maintain a competitive advantage while actively maintaining support for the old standard. These organizations are likely to operate in an environment where extensive legacy support is required while certain features of the new standard provide some competitive value for the adopting organization. For example, an organization with a large EDI infrastructure in a financial industry where EDI is dominant might choose to also adopt XML to support a niche market (such as the delivery of financial information to wireless devices). However, the organization will continue to maintain support for EDI as their main method of intra-organizational data exchange as long as it is required by the environment. Firms in this case could gradually phase out the old standard, but might remain in the coexistence state for an extended period of time if market forces demand it.

Next, we apply the ISA model to a new Internet standard – IPv6. In the following section we describe the technical characteristics of IPv6. We then describe each mode of adoption as it applies to the adoption of IPv6 by ISPs.

THE CASE OF IPV6: AN UNADOPTED STANDARD

IPv6, also known as Internet Protocol next generation (IPng), is the first major standard introduced by the IETF[4] and the Internet Society since the privatization of the Internet in

[4]The IETF (http://www.ietf.org) can propose standards but has no authority to enforce them, nor does it have funding to financially support their implementation.

		Conduciveness of environment to adoption of a/the new standard (EC)	
		Low	**High**
Usefulness/ need of features of new standard (UF)	**Low**	I. **Status quo** *Stay where you are*	III. **Replacement** *Implement but with no new features – use like the old technology*
	High	II. **Co-existence for best use** *Implement with some but not all features, and support both in the transition*	IV. **Full implementation** *Implement new standard with all of the features*

Figure 5. Adoption through coexistence.

1992. IPv6 is a particularly interesting standard to study because it typifies the interplay of interrelatedness and autonomy which characterizes the Internet. IPv6 lies at the network layer of the OSI model, and therefore serves as an underlying component of most Internet-based communication. Therefore, it requires high levels of interrelatedness and integration among adopters. This is in contrast to standards that operate in the application or presentation layers of the OSI model (such as XML), which can achieve integration through additional application modules. At the same time, the adoption of IPv6 is not driven by a central entity (such as DARPA), leading to autonomous and independent adoption decisions by various stakeholders (e.g. equipment vendors, software vendors, and ISPs).

The current state of IPv4

The limitations of IP, the standard protocol used for Internet communication, illustrate some of the scalability problems faced by the Internet. These limitations are evident in the current version of IP (called IPv4), which include (Microsoft, 2000):

1 There are a limited number of available new addresses. The number of addresses that can be allocated using IPv4's addressing scheme is rapidly dwindling, exacerbated by increasing worldwide demand. In addition, the class structure and class-based address allocation limit the

available addresses to new entrants. Currently, 74% of existing address classes is allocated to entities in the USA and Canada (Goodin, 2001).[5]
2 The flat address structure of IPv4 results in large, flat routing tables. As the number of allocated addresses increase, search time also increases, slowing the response time of routers.
3 There is no traffic prioritization (often referred to as 'Quality of Service') for the smooth transmission of multimedia data. Current IP traffic is transmitted on a first-come, first-serve basis regardless of the type of data involved. This means that email messages and file transfers, which are asynchronous transmissions that do not require consistent delivery, have the same priority as a video conferencing stream which requires consistent delivery.
4 IPv4's basic security is poor, relying on 'ad hoc' solutions. IPv4 does not mandate the use of IPSec, the current standard for security for IP-based communications.

In addition:

1 Implementing Internet-based mobile computing over IPv4 is complex.[6]
2 Multicasting capabilities in IPv4 are limited.

Separate solutions have been developed to address each of these issues individually, each introduced through the standards process. For example, network address translation (NAT) was developed to alleviate addressing shortages, high-bandwidth solutions such as DSL and cable were introduced to improve the performance of multimedia applications in the absence of prioritization, and Secure Socket Layer (SSL) technology has been developed to compensate for IPv4's security shortcomings. However, a comprehensive solution in the form of a new standard, IPv6, has been proposed by the IETF. The first call for comments on the IPng was published in 1993 (RFC 1550). Subsequent RFCs refined the requirements of IPng in areas such as multicasting (RFC 1667), cellular capabilities (RFC 1674) and security (RFC 1675), and its impact on various stakeholders such as large corporate networks (RFC 1678), ATM services (RFC 1680) and cable television (RFC 1686). IPv6 specifications were proposed as a standard by the Internet Society in December 1998 (RFC 2460). The new protocol offers a larger address space (Metcalfe, 1998), simplified configuration, Quality of Service capabilities, improved routing, built-in security and mobile capabilities. Further details comparing key features of IPv6 to IPv4 are provided in Appendix A.

To fully understand why a particular environment may be more conducive to the adoption of IPv6, we apply the proposed ISA framework. A summary of the key features of IPv6 and their potential impact on ISPs are provided in Appendix B.

[5]IP addresses are allocated to ISPs in blocks. The initial allocation, before the privatization of the Internet, was of full classes. Many companies and organizations were able to secure a full class A or a full class B. As a result all class A and B are either allocated or reserved. All the remaining available IP addresses are from class C blocks. These classes are currently allocated in blocks of 64 addresses at a time (half a class).
[6]Current implementation of mobile IPv4 requires the use of a foreign agent (FA), a home agent (HA), and a care-of (CO) address. The FA has to communicate that address through a tunnel back to the HA on the user's home network. Currently, packets from the corresponding node to the mobile unit always have to go through the HA. Because IPv6 supports auto-configuration, the implementation of mobile IPv6 is less complex.

THE APPLICATION OF THE ISA MODEL TO IPV6

In this section, we will apply the ISA model to predict potential adoption patterns for IPv6 by ISPs – that is, the model is used to analyse the adoption decision of an ISP. According to our model, the decision to adopt depends upon the ISP's environment and the UF to that ISP. We will describe each of the four adoption modes in the ISA model (status quo, adoption through replacement, adoption through coexistence, and full implementation) in the context of IPv6 adoption.

Although the unit of analysis is an individual ISP, there will likely be some degree of correspondence between geopolitical boundaries and the environment of a given ISP. There are several reasons for this association:

1 North America and Western Europe have already acquired much of the IPv4 address space (which were originally assigned on a 'first come, first serve' basis). Therefore, the current allocation of IP addresses varies widely by geographic location.
2 Government sponsorship is limited to a given country (e.g. India or China) or to a region (e.g. the European Union).
3 In many countries, ISPs are controlled by the national telecommunications organization which is regulated and managed by their respective governments.

However, not all ISPs in a given country or region will necessarily follow an identical adoption mode or path. One ISP in a given region may have different levels of drag, inertia, or sunk cost than another ISP in the same region. For example, an ISP in the USA might have a large base of older technology because it took over some of the original infrastructure of the Internet, while another ISP in the USA might have very new technology that is fully compatible with IPv6. In addition, different ISPs will view the UF of the standard differently depending on their customer base and strategic intent.

Status quo

This case is characterized by low EC and low UF. Therefore, ISPs in this case choose to stay with their current infrastructure, implementing a 'wait and see' approach towards the adoption of IPv6. These ISPs operate in an environment with a high installed base of IPv4 technologies and related infrastructure. IPv4 may be the prevailing standard not only for the ISP itself, but also for its vendors and customers, producing high drag, inertia, and conversion costs. There may be limited or non-existent network externalities because other ISPs in this environment have also adopted a 'wait and see' strategy. With limited adoption and experience with the implementation of IPv6, the amount of information and knowledge available about the new standard is limited. These ISPs are also likely to operate in environments that have no sponsorship, resulting in little or no incentive (monetary or regulatory) to adopt IPv6. In addition, the lack of IP addresses may not be a problem for these ISPs as they may already have significant control over that scarce resource or there is little demand for new IP addresses. In such situations, EC to adoption is low.

In addition, ISPs in this case will not see much value in the features of IPv6. ISPs that have significant investments in legacy systems (such as the US military, which owns parts of the original ARPANET) are likely to operate with an infrastructure that is not compatible with IPv6. This incompatibility increases the complexity of the upgrade process and reduces the ability to test, observe, and quantify the benefits of IPv6. Creating test beds to measure the trialability and observability of IPv6 is not a justifiable investment if the ISPs do not see a strategic advantage in adopting any of the features of IPv6. This may be because of lack of interest by their current clients, because either their clients' infrastructure is IPv4-based, or because there is little or no demand for new services that require the new standard. Therefore, the UF is low. In summary, an ISP that operates in an environment with low conduciveness to the adoption of IPv6 and sees little use for its features will most likely remain with its current IPv4 infrastructure.

IPv6 is used with IPv4, depending on best use ('adoption through co-existence')

This case is characterized by low EC and high UF. Therefore, in this case, ISPs will reach full adoption of IPv6 by using IPv4 and IPv6 in parallel, based on the specific demands of individual consumer groups. These ISPs operate in an environment with a high installed base of IPv4 technologies and related products. IPv4 is the prevailing standard for the ISP itself, for its vendors, and for some of its customers, thus producing high drag, inertia and sunk costs. Because ISPs in this environment will be installing IPv6 infrastructure for niche markets, network externalities and the availability of information evolve around these markets. ISPs in the 'best use' case may create application-specific consortia (such as the Internet 2 consortium). This creates limited sponsorship, resulting mostly in the promotion of IPv6 for a particular niche. These ISPs operate in an environment where there is a large supply of IP addresses, or the availability of IP addresses only interests these ISPs if a large number of addresses is required for a specific application it intends to offer (such as 3 G cellular phones, with 'always-on' Internet connections). Therefore, the EC to adoption will be low.

The 'adoption through coexistence' path is characterized by the existence of niche applications that demand the implementation of features available through IPv6. This will increase the value of IPv6 to ISPs that offer these services. Examples of such applications include embedded technologies and wireless Internet devices. It has been predicted that 40% of homes within the next, 10 years will, to some extent, be smart homes (themovechannel.com, 2000). Smart appliances will each have their own IP address, significantly increasing the demand for the additional address space that IPv6 can provide. Smart appliances also rely on technologies such as Sun Microsystems' Jini, which require multicasting capabilities. Similarly, mobile Internet connectivity solutions utilize dynamic host configuration while interactive multimedia applications (such as virtual reality) utilize Quality of Service capabilities. Therefore, ISPs that service these niche markets see relative advantage in the various features afforded by IPv6. ISPs in this case find it necessary to create test environments and assess the technological and economic feasibility of the new standard (influencing trialability and observability). In summary, these ISPs are likely to see a competitive advantage in adopting certain features offered by IPv6 to service niche markets (high UF), but due to significant existing investments in IPv4 (low EC) may run the two protocols concurrently.

IPv6 works like IPv4 ('adoption through replacement')

This case is characterized by low UF and high EC. ISPs in this environment are likely to adopt IPv6 by default for the following reasons:

1. IPv6 is the latest standard for TCP/IP-based communications.
2. IPv6 is bundled with products such as routers and network operating systems.
3. IPv6 is bundled with leading desktop operating systems (such as Windows and Linux).

However, ISPs in this case do not utilize the features of IPv6 to gain a strategic advantage. These ISPs operate in an environment with a low previously installed base of Internet-related technologies, or in environments where IPv4 is not likely to be the prevailing standard. The result is low drag and inertia with little or no sunk cost.

These environments are also more likely to be characterized by a lack of IP addresses, making it a scarce resource as the majority of the IP address blocks have already been allocated. Local sponsorship may be negligible if there are limited financial resources to support major Internet initiatives. However, there may be external sponsorship, such as the United Nations' initiatives to help developing nations with the implementation of technology (Gruenwald, 2001), which can encourage the adoption of IPv6. In summary, the EC is high.

ISPs in this case see little value in the features of IPv6 because the ISPs have limited markets for the capabilities offered by these new features. The complexity of upgrading is low because there are no legacy systems, and therefore compatibility issues are likely to be minimal. The value of observability and trialability are low given the ISPs' low interest in the strategic value of the new features of IPv6. In summary, ISPs will adopt IPv6 because it is simply the newest standard, but because of the low UF they will not take full advantage of its capabilities.

IPv6 full implementation

This case is characterized by high UF and high EC. Although full implementation of IPv6 can be achieved through one of the two paths described above, some ISPs may move directly to full implementation without first going through a partial implementation. ISPs that adopt a full implementation strategy are likely to operate in an environment with a low installed base of existing Internet infrastructure where IPv4 is not a prevailing standard. This results in low drag and inertia, and little or no sunk costs. These environments are likely to have some government sponsorship in the form of financial incentives or mandates, resulting in communication and information sharing among ISPs. In addition, we anticipate that these ISPs have a limited number of available IP addresses. Thus, their potential growth and continued operation depends on a resource that is scarce and controlled by others. The result is a high level of EC.

ISPs that choose to fully implement IPv6 are likely to have seen value in the features of the new standard. The lack of a significant legacy infrastructure mitigates most compatibility issues, also reducing the complexity of the upgrade. For example, ISPs that operate on newer IPv6-compatible Cisco routers require minimal effort to upgrade. Because of the low complexity, the ability of the organization to test, observe, and quantify the benefits of IPv6 is relatively high, resulting in better understanding of the benefits of this standard. It is likely that these ISPs will be given financial incentives from their governments to create test environments, leading to a higher ability of these firms to determine the strategic advantages in adopting most or all of the features of IPv6. Overall, the UF for these ISPs is high. In summary, an ISP can exploit emergent high technology markets using the new features of IPv6 to create new products and services.

Thus far our analysis shows that an ISP may operate in an environment that is not conducive to the adoption of IPv6 because of an extensive existing infrastructure, absence of a resource crisis (i.e. a lack of IP addresses), or an absence of sponsorship. Within that environment, an ISP determines the UF of the new standard and then decides on an adoption mode. For example, an innovative ISP in an environment with low conduciveness might ultimately decide to adopt IPv6 (quadrant II in Figure 6) because they see value in the features where other ISPs in the same environment choose not to adopt (quadrant I in Figure 6).

Alternatively, different ISPs that have a similar level of usefulness of the standard's features may make different adoption decisions based on their environment. For example, an ISP that does not see significant benefits in the new features of IPv6 (low UF) but operates in an environment with high conduciveness (high EC) might choose to adopt IPv6 but not develop new services using any of those features (quadrant III in Figure 6). An ISP that does not see significant benefits in the new features of IPv6 (low UF) and operates in an environment with low

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Conduciveness of environment to adoption of a/the new standard (EC)</td></tr>
<tr><td>Low</td><td>High</td></tr>
<tr><td rowspan="2">Usefulness/ need of features of new standard (UF)</td><td>Low</td><td>I. Status quo
ISPs in markets with a well-developed infrastructure</td><td>III. Replacement
ISPs in markets without an extensive existing infrastructure</td></tr>
<tr><td>High</td><td>II. Co-existence for best use (niche)
ISPs serving niche markets</td><td>IV. Full implementation
Emerging ISPs in technically oriented markets</td></tr>
</table>

Figure 6. The application of the ISA model to IPv6.

conduciveness (low EC) may elect not to adopt IPv6 at all (quadrant I in Figure 6). For example, two ISPs may face varying EC within the USA because the extensiveness of their IPv4 infrastructure differs, resulting in different levels of drag.

ISA model applied to other standards

Although the focus of this paper has been IPv6, the proposed ISA model is applicable across multiple Internet standards. A comprehensive analysis of another Internet standard is beyond the scope of this paper, however, in this section we briefly describe the application of the ISA model to the adoption of XML. The adoption of the XML standard can be considered within the context of both EC and the usefulness of its features. XML offers advantages over past methods for the exchange of structured data over the Internet. Applying this directly to our framework, we arrive at the following four modes of adoption for XML (Figure 7):

1 **Status quo** – These firms will have extensive investment in legacy EDI systems, with no clear identifiable advantage to XML. They are likely to avoid implementing XML, choosing to continue supporting their existing EDI system.
2 **Adoption through co-existence** – In this case firms have a significant investment in EDI, but also have key partners who use specific XML-based applications, such as ebXML or NewsML. To be fully interoperable with both systems, the organization keeps both standards, maintaining the ability to communicate with all external systems in their 'native' format.
3 **Adoption through replacement** – These firms have a need for information exchange, have little or no investment in existing EDI systems, but do not require the specific benefits afforded

		Conduciveness of environment to adoption of a/the new standard (EC)	
		Low	**High**
Usefulness/ need of features of new standard (UF)	**Low**	I. **Status quo** *Extensive investment in EDI, no clear advantage to XML*	III. **Replacement** *Need for information exchange, little or no existing EDI investment*
	High	II. **Co-existence for best use (*niche*)** *Significant investment in EDI, XML offers advantages for some applications*	IV. **Full implementation** *Little existing EDI investment, and strong business case for XML*

Figure 7. The application of the ISA model to XML.

by XML. The organization will need to communicate with other firms who may use either XML or EDI. XML will be used for messaging only because it is the current default standard, but the implementation will need to be compatible with both types of external systems via transitional technologies.

4 Full implementation – In this case firms have little existing EDI infrastructure and few of their partners still use EDI, creating low barriers to the full adoption of XML. These firms also have a strong business case for implementing XML. Therefore, they are likely to fully implement XML, taking advantage of most or all of its features.

DISCUSSION

One of the goals of this work was to examine the factors that influence adoption of standards in the context of the Internet. Our development of the ISA model and its application to IPv6 reveals several areas in which we gain new insights into the adoption of that protocol, and the adoption of Internet standards in general. In this section, we will present those insights. Our analysis also revealed the significant influence governments and other sponsors can have on the adoption pattern of Internet standards. We therefore discuss a set of recommendations for firms and governments interested in facilitating the adoption of IPv6. We conclude our discussion with future research directions that can be investigated using the proposed model.

Partial adoption as a 'persistent' state

The traditional notion of adoption of innovation literature is that the adoption decision is dichotomous. This view was critiqued by Bayer & Malone (1989), but has not been further developed. Our analysis not only supports the concept of a partial adoption (Bayer & Malone, 1989) in the context of Internet standards, but also identifies two possible modes of partial adoption. For example, we suggest that some ISPs might adopt one or two features of IPv6 to serve a niche market while maintaining their IPv4 infrastructure for the rest of their market, creating a long-term and stable state of partial adoption.

An integrative model

The case of IPv6 shows that the two dimensions that comprise the ISA model, EC and the UF, must be taken together to fully understand the diffusion pattern of Internet standards. Considering only one of the dimensions can lead to misconceptions. For example, an ISP operating in North America could be considered to have low 'EC' to the adoption of IPv6. Considering EC alone might lead to the assumption that *all* ISPs in an environment with low conduciveness will adopt a 'wait and see' strategy, leading to the assertion that *all* ISPs in the USA will refrain from adopting IPv6. However, ISPs with low EC servicing a niche that uses some of the features of IPv6 (high UF) are likely to adopt IPv6 concurrently with IPv4. Thus, in the USA, innovative ISPs or ISPs involved with advanced Internet technologies will most likely adopt IPv6 in parallel with their IPv4 infrastructure. Taken separately, each factor only describes part of the adoption decision, while together the two dimensions provide a comprehensive view.

Geopolitical boundaries

An unexpected finding of our analysis is that despite the fact that the Internet does transcend geographical boundaries, these boundaries do have an impact on the adoption decisions of ISPs. This influence is primarily reflected in the importance of sponsorship and resource availability, both components of EC. Our analysis indicates that:

1 Most IPv6 sponsorship is based within discrete geopolitical boundaries. This is partially because of the fact that in many countries, ISPs are owned by (or strongly tied to) governmental telecommunications agencies.
2 Some governments sponsor Internet initiatives because they see the Internet as a tool to achieve economic and strategic advantage. For example, the Indian government is funding a project that will support the deployment of IPv6. This project will connect networks in India to IPv6 networks in Japan and Europe, developing network externalities by creating a transcontinental IPv6 backbone and providing increasing returns to adoption of the new standard (Schwankert, 2001).
3 The Internet started in North America and Western Europe. Most blocks of IP addresses (class A and class B) were allocated in the 1980s to organizations in these regions, leaving a limited number of blocks for other regions. This has resulted in a large disparity in IP address allocation along geographical boundaries. In addition, the supply of current IP addresses is finite. Although supplemental technologies such as NAT can alleviate this problem, it is an impractical solution for creating a set of addresses for an entire geographic region. There are no ways to increase the fundamental number of addresses without moving to IPv6.
4 Most ISPs in North America and Europe have a larger investment in the current IPv4 infrastructure, while underdeveloped countries have very limited investment in IPv4. This has created differences in drag, inertia, and sunk costs. Therefore, it is possible that an ISP in Africa, where there is little or no investment in the current IPv4-based infrastructure or substitute technologies, is more likely to adopt IPv6 as a default technology than an ISP in North America.

Recommendations

Our analysis implies four measures that governments and vendors can undertake to facilitate the implementation of Internet standards in general and IPv6 in particular. Specifically, there are implications for sponsorship and policy setting. The analysis also provides support for encouraging products that are 'backwards-compatible' and developing transitional and related technologies.

Sponsorship

The decentralized nature of the Internet makes sponsorship extremely important. The infrastructure must be created to generate network effects so that firms will begin to use the standard. Sponsorship can come in the form of government financial assistance, in the form of regulations, or it can provide needed uniformity by creating the necessary infrastructure. In environments where government involvement is minimal, vendors can introduce sponsorship by creating and supporting industry-wide consortia. Thus, encouraging the creation of test environments will increase network externalities and the flow of information. For example, the Internet 2 consortium (supported by private companies) provides limited sponsorship, and is deploying high-speed connection points called 'gigaPOPs' that support IPv6 (Thompson, 2002). Abilene, as part of Internet 2, is an example of an IPv6-based network that connects approximately 200 universities. One of the applications being tested using Abilene is voice over IPv6 using the VOICE6 protocol.

Policy setting

Incompatibility can impede the exchange of messages over the network, which is central to a communications-based environment such as the Internet. Thus, governments and other policy-setting bodies should determine their long-term strategic goals in relationship to the Internet and adopt policies that will ensure the ability of their constituents to communicate in the future. For example, although Western Europe's existing infrastructure acts as a disincentive to adopt IPv6, the European Union has created directives and set policies and timelines for the adoption of IPv6. In addition, governments should assess the availability of their resources (e.g. IP addresses in the case of IPv6) and propose initiatives that will increase the availability of these resources.

Encourage 'backwards-compatible' products

To support the adoption of new Internet standards, it is recommended that vendors create products compatible with previous standards. This can be done by explicitly making products 'backwards compatible', or by building extensible, open systems with common interfaces that can be augmented with minimal effort. The availability of compatible systems allow companies to introduce the new standard in stages (such as in the case of 'adoption through coexistence') while replacing technologies that are based on the old standard through attrition. This can encourage future adoption because it reduces drag and sunk costs.

Encourage transitional and related technologies

To achieve full adoption through either path there is a need for transitional support between the old and the new standard. Therefore, a 'transitional infrastructure' should be developed by Internet companies and made easy to implement. Transitional technologies refer to network components that allow IPv4 and IPv6 to communicate seamlessly by supporting both versions of the protocol. In addition, vendors that are interested in promoting the adoption of IPv6 should create products that take advantage of its capabilities leading to the increase of the standard's relative advantage. An example of an ISP that has implemented a transitional infrastructure is

Nippon Telegraph and Telephone Corporation (NTT). NTT implemented IPv6 with tunneling into IPv4 (Ezaka & Shibata, 2002). This infrastructure allows consumers that are using IPv6 to communicate on IPv4-based networks (and vice versa). By implementing such an infrastructure, NTT is able to sell transitional services to ISPs and other users.

Future research

It should be noted that an underlying assumption of the ISA model is that a standard has multiple features that can be unbundled. It is possible that the model may have to be modified if a standard has only one feature or if its features cannot be implemented separately. In addition, we applied our model to IPv6, which is a network layer protocol. It therefore requires significant interoperability among players. It is possible that other Internet standards that require less interoperability might exhibit different behavior. Future research should apply the ISA model to various types of Internet standards (as we have started with our brief description of its application to XML).

Each case described in this paper was essentially a ‘pure’ case. In each case, all the elements of each dimension (the EC and UF) align with the overall direction of that dimension (‘low’ or ‘high’). For example, in the ‘status quo’ case (quadrant I), all the elements of EC implied that the dimension would be ‘low.’ In reality, there may be cases where some elements will push the dimension in the opposite direction. For example, there could be an environment with high drag, inertia, and sunk cost (leading to low EC) but also high sponsorship and a lack of available resources (leading to high EC). Future research is necessary to determine the level of importance (or the relative weight) of each element within the EC and UF dimensions.

Another avenue for future research is to verify the model through empirical studies. This verification can either be done through the development of a typology of international ISPs or through collection of quantifiable data.

SUMMARY

The Internet presents new challenges in understanding the diffusion of standards. The lack of central control and the need for interoperability provide a unique backdrop for the introduction of new innovations. In this paper, we developed a model for the adoption of Internet standards. The ISA model draws on diffusion literature to suggest that two major dimensions influence the mode of adoption. These two dimensions characterize the conduciveness of the environment to the adoption of the new standard (EC) and the UF of the standard to adopting firms (UF). Each dimension taken alone only explains part of the adoption behavior of organizations in the context of the Internet.

The ISA model also introduces four potential cases of adoption. Two of these cases are the traditional dichotomous notion of full adoption and non-adoption. In addition, the notion of partial adoption is introduced by illustrating two ‘paths’ to full adoption. One path, ‘adoption through coexistence’, describes the situation where the new standard is introduced in order to take advantage of its functionality for a niche group, while support for the old standard is maintained for the remainder of the market. The other path, 'adoption through replacement', describes the situation where the old standard is replaced with the new one by default, but adopters do not take advantage of its additional functionality.

From our analysis, we demonstrate how 'geopolitical location' plays a significant role in influencing the adoption process in the case of Internet standards. This construct has not been introduced in the current adoption literature. What is interesting about this new construct is that it contradicts the belief that the Internet transcends geopolitical boundaries.

The ISA model can potentially be applied to a number of emerging Internet standards. Our analysis of the IPv6 case (as illustrated in Figure 5) indicates that ISPs in environments with low conduciveness to adoption will most likely be reluctant to implement IPv6, or will implement it only for a niche market while maintaining their current investment in IPv4. ISPs in environments with high conduciveness, with either a low level of investment in IPv4, a need for large number of IP addresses, or strong sponsorship, will be leading the commercial implementation of the new protocol. ISPs in environments that have an extensive IPv4 infrastructure are most likely to support both standards for a period of several years. ISPs in environments with less of an investment in IPv4 are more likely to move to a full implementation of the new standard first.

Although the model aims at explaining diffusion of an Internet standard, it can also be used to profile different market segments and help organizations (such as ISPs) position themselves depending on their strategic orientation. The dimensions identified in the model can be used to develop a diagnostic tool for managers to assess where to position themselves in the market.

In addition, governments and other policy-setting organizations can use the model to set policies and guide the creation of consortiums. They can do this by assessing the conduciveness of their own environment to the adoption of a new standard, and by making policy decisions accordingly. Thus, the ISA model can serve as a means for extending diffusion research to accommodate the complexity of the Internet. The ISA model can also be used as a framework for Internet vendors, policy-making groups, and organizations to guide the strategic decisions that will encourage the adoption of Internet standards.

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APPENDIX A COMPARISON OF IPV6 TO IPV4*

Category	Advantage of IPv6	Why it is important
Addressing	The address space in IPv6 is much larger than IPv4 (16 bytes instead of 4 bytes). This means that IPv6 allows for 3.4×10^{38} addresses, compared with 4.2×10^{9} possible addresses with IPv4.	The number of unique IPv4 addresses is dwindling rapidly. This is mostly a problem in undeveloped countries.† It is also anticipated to become a problem if the 3 G wireless standard replaces the current 2.5 G and if smart homes proliferate.‡
Configuration	A client running the IPv6 protocol can automatically configure itself with a unique address, eliminating the need for static addresses or previous methods of auto-configuration such as Dynamic Host Configuration Protocol (DHCP).	The management of multiple IPv4 clients within an organization involves tracking the assignment of addresses either for each client, or for 'pools' of clients.
Data delivery	There are new header fields in IPv6, which indicate the type of information being sent within each packet. This information can be used to prioritize traffic and guarantee Quality of Service (QoS).§ However, it is important to note that the actual implementation of QoS is still in the 'research and development' stage as IPv6 alone is not sufficient for implementing end-to-end QoS.	For the transmission of multimedia data over the Internet, the fast and reliable delivery of IP packets is critical. Prioritization is one method of increasing speed and interactivity within the existing network topologies.
Routing	IPv6 packets are moved from segment to segment using a simplified, hierarchical routing structure.	Routing under IPv4 is only partially hierarchical, relying also on large flat routing tables that can exceed 70 000 entries. Routing under IPv6, with its significantly smaller routing tables, requires less overhead at the router and is therefore more efficient and faster.

APPENDIX A *cont.*

Category	Advantage of IPv6	Why it is important
Security	IP security standards (IPSec), previously optional under IPv4, are now required under IPv6.	Standardized, layer 2 security reduces hacking activities.
Mobile	Current implementation of mobile IPv4 requires the use of a foreign agent (FA), a home agent (HA), and a care-of (CO) address. The FA has to communicate the CO address through a tunnel back to the HA on the user's home network. The packets from the corresponding node to the mobile unit always have to go through the HA. Because IPv6 supports auto-configuration, mobile IPv6 is simpler.	ISPs support wireless devices such as PDAs and Pocket PCs in increasing numbers.
Multicasting	The built-in multicasting in IPv6 allows a server to send a single packet with multiple addresses. The ISP will do the final routing.	Allows several levels of multicasting and the creation of routing trees. This is a more efficient routing mechanism for applications such as Jini, which depend upon the ability to 'discover' compatible devices on the network.

*Adapted from Microsoft Corporation (2000).

†In Pakistan, a 'class C' cost $1050 to $1275 a year (in 2000). Because of lack of addresses, the price of a 'class C' almost doubled. In 2002, a class C cost $1900–2300 a year.

‡'Smart' Homes for Smart People by Reuters. 9:10 AM 2 February 1999 PST http://www.wired.com/news/business/0,1367,17676,00.html. [Accessed 16 September 2003].

§Blazing trails: By paving paths for packets, MPLS could clear the way for IP convergence. Margot Suydam, Technology Editor – *CommVerge*, 1 May 2002. http://www.reed-electronics.com/ednmag/index.asp?layout = article&articleid = CA214592&rid = 0&rme = 0&cfd = 1. [Accessed 16 September 2003].

APPENDIX B IPV6 FEATURES AND THEIR IMPACT ON ISPS

Factor	Current status	Evaluation
Relative advantage	See Appendix A for fora list of technical advantages.	Various ISPs will adopt the standard based on their business needs. For example, a given ISP might adopt IPv6 because they lack IP addresses. Other ISPs might be looking for the mobile services afforded by the new standard. The more advantages the features of IPv6 provide to an ISP, the more likely they are to fully implement the new standard.
Compatibility (backwards)	In theory, Ipv6 was designed to be compatible with IPv4. There are several mechanisms that support coexistence of the two protocols. Running both networks requires specialized hardware and software.	In cases where the current infrastructure is more compatible with IPv6, it is more likely to be adopted. For example, young ISPs use relatively new equipment that is compatible with (or that can be easily upgraded to) IPv6. Universities who were on the original ARPANET may have old equipment that would need to be completely replaced.

APPENDIX B *cont.*

Factor	Current status	Evaluation
Complexity (Managing and upgrading)	IPv4's maintenance is complex (e.g. NAT does not work with all applications, and IPv4 requires the manual maintenance of routing tables). The maintenance of IPv6 is likely to be less complex. In areas with relatively new infrastructure, the upgrade from IPv4 to IPv6 is relatively simple. However, service providers with an extensive and older infrastructure will have difficulties upgrading. Thus the management of the transitional network in those cases may also be more complex.	Similar to compatibility, in some cases the transition is more complex than in others. Where the transition is very complex, ISPs will be reluctant to upgrade.
Trialability	Test beds exist in several environments. Europe and Japan are leading in that area. Examples are 6BONE, BT-Japan, and 6NET.	Environments are more conducive to adoption of IPv6 where test-beds proliferate, and where there is an extensive sharing of trial information. ISPs that have access to trial data are more likely to adopt the new standard.
Technology interrelatedness	A limited number of technologies that take advantage of IPv6 exist. Several developments by Microsoft are forthcoming. In Europe the deployment of the 3 G wireless phone standard is heavily related to the deployment of IPv6.	ISPs that have related technologies available to them are more likely to adopt the new standard. For example, ISPs that intend to offer Internet services to 3 G wireless devices are more likely to adopt IPv6 than a traditional ISP serving mainly dial-up and DSL connections.