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MIGRATION TO OPEN-STANDARD INTERORGANIZATIONAL SYSTEMS: NETWORK EFFECTS, SWITCHING COSTS, AND PATH DEPENDENCY[1]

By: **Kevin Zhu**
The Rady School of Management
University of California, San Diego
La Jolla, CA 92093-0093
U.S.A.
kxzhu@ucsd.edu

Kenneth L. Kraemer
The Paul Merage School of Business
University of California, Irvine
Irvine, CA 92697-3125
U.S.A.
kkraemer@uci.edu

Vijay Gurbaxani
The Paul Merage School of Business
University of California, Irvine
Irvine, CA 92697-3125
U.S.A.
vgurbaxa@uci.edu

Sean Xin Xu
School of Business and Management
Hong Kong University of Science & Technology
Hong Kong
CHINA
seanxu@ust.hk

Abstract

As firms seek to improve coordination through the use of electronic interorganizational systems (IOS), open standards are becoming increasingly important. To better understand the process of standards diffusion, we investigate firms' migration from proprietary or less-open IOS (i.e., electronic data interchange or EDI) to open-standard IOS (i.e., the Internet). Theoretical work in economics suggests that network effects are a determinant of network adoption, yet the extant literature falls short of empirical testing of the theory. We develop a conceptual model that features network effects, expected benefits, and adoption costs as prominent antecedents. We examine the model on a large dataset of 1,394 firms. The empirical results demonstrate the significant impacts of network effects on open-standard IOS adoption. We find that adoption costs are a significant barrier to open-standard IOS adoption, but EDI users and nonusers treat this very differently: EDI users are much more sensitive to the costs of switching to the new standard. This finding illustrates that experience with older standards may create switching costs and make it difficult to shift to open and potentially better standards, a phenomenon called "excess inertia" in technology change. Further testing the underlying factors that contribute to network effects and adoption costs, we find that trading community influence is a key driver of network effects, while managerial complexity, as opposed to financial costs, is a key determinant of adoption costs. Overall we believe that this study, based on a rigorous empirical analysis of a unique international dataset, provides valuable insights into a set of key factors that influence standards diffusion.

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Keywords: Open standards, standards diffusion, network effects, switching costs, path dependency, interorganizational systems, Internet, electronic data interchange, economics of standards

Introduction

With the fast development of open standards, firms are increasingly deploying interorganizational systems (IOS) to facilitate collaboration with their suppliers and trading partners. The dramatic reduction of costs in communications has further promoted the wide application of networked organizational forms (Hacki and Lighton 2001). The trend in industry is that firms are migrating toward value networks that hold the promise of substantial productivity gains (Greenspan 2002). Today, the widespread network access, associated with the increasing scale of information technology (IT) use, has substantially heightened the potential value to firms from the networked partnerships (Shapiro and Varian 1999a), focusing renewed attention on the importance of open standards.

Standards have consistently played an important role in IT adoption and diffusion (Shapiro and Varian 1999b). It has been widely noted that innovations related to standards are a primary driver of industrial productivity (David and Greenstein 1990). To fully realize economic value from promising standards, their diffusion in industry is a critical step beyond standards development (Rogers 1995); without wide adoption among firms, the benefits resulting from their invention will be curtailed (Zhu et al. 2006a). New standards adoption is also an important undertaking for individual firms, because adopting successful new standards can help a firm seize significant competitive edge (Katz and Shapiro 1994; Zhu 2004); on the other hand, a firm "trapped" in an old standard or lagging in adopting technologies based on new standards may lose competitive advantage (Shapiro and Varian 1999b; Zhu and Weyant 2003). Therefore, understanding standard adoption stands out as an important research topic at the firm level (Lyytinen and Rose 2003). In-depth study on this topic may help broaden our understanding about the entire process of standards making (David and Greenstein 1990).

Electronic data interchange (EDI)[2] systems have been adopted in a variety of industries since the 1970s (Iacovou et al. 1995; Riggins et al. 1994). More recently, the Internet, facilitated by the development of open standards such as the Transmission Control Protocol/Internet Protocol (TCP/IP) and eXtensible Markup Language (XML), has steadily become a popular platform for interfirm coordination (Shapiro and Varian 1999b). Internet-based systems, as exemplars of open-standard IOS, are widely regarded as one of the most significant IOS innovations (Chatterjee et al. 2002). In this study, *open-standard IOS* refers to the kind of interorganizational system that uses open standards (e.g., XML-based data standards and TCP/IP as the communication protocol) and is built upon a public, open network (i.e., the Internet). According to a recent survey (Varian et al. 2002), open-standard IOS diffuse much faster among firms than did EDI, and is becoming the dominant model for business-to-business transactions. Figure 1 shows such a trajectory of IOS migration from proprietary standards to open standards.

Along this trajectory, the migration from paper-based manual systems to paperless EDI has been studied extensively in the literature (e.g., Iacovou et al. 1995; Mukhopadhyay et al. 1995; Teo et al. 2003). In contrast, the migration to open-standard IOS remains an under-studied area (Kauffman and Walden 2001). Given the open-standard nature of the Internet, potential adopters comprise a much broader trading community. Thus, a key characteristic of network behavior, namely *network effects*, should theoretically play a more significant role (Shapiro and Varian 1999b). Yet this has not been tested empirically in the literature.[3] Further, consistent with the notion of *path dependency* (Arthur 1989; Cohen and Levinthal 1990), a firm's prior experience with EDI may influence its adoption of new open-standard IOS. For example, prior use of EDI could facilitate a move to open-standard IOS because of a company's experience with technology-enabled interfirm collaboration, or it might inhibit such a move because of the limited flexibility of existing EDI systems (Swanson 1994). However, no empirical research has examined path dependency in the information systems standards literature. In our literature review, we could find no empirical studies that incorporated different migration pathways, and thus we know very little about how the pattern of open-standard IOS adoption varies between firms with and without EDI experience.

Seeking to narrow this gap, our research examines firms' migration from EDI systems to Internet-based IOS. We draw upon *network effect* theory from economic literature (Katz and Shapiro 1985, 1986, 1994) to study this migration. Key

[2]Electronic data interchange (EDI) is the interorganizational, computer-to-computer exchange of business documentation in a standard, machine-processable format. In general, EDI standards include the data standard (format of messages) and the communication protocol. EDI typically transmits data over private networks or value-added networks (VANs) (Emmelhainz 1993).

[3]Gurbaxani (1990) has shown empirically the impact of network effects on the adoption of BITNET, an open-standard precursor to the Internet.

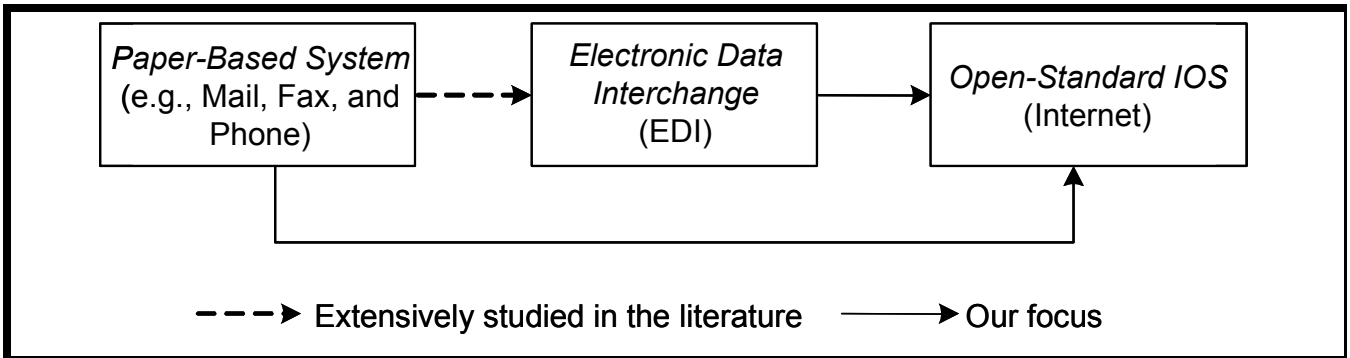

Figure 1. The Trajectory of IOS Migration

research questions that motivate our work are: What factors facilitate or inhibit firms' migration to open-standard IOS? To what extent is this migration influenced by network effects and adoption costs? How does prior EDI experience affect the adoption of open-standard IOS?

To better understand these issues, we develop a conceptual model grounded in network effect theory in conjunction with a path dependency perspective. We derive a set of hypotheses from the model, and test these hypotheses on a large and unique data set of 1,394 firms from 10 countries. The paper is organized as follows. We first describe the phenomenon of interest: the trajectory of IOS migration. Then, we present our theoretical perspectives, develop our conceptual model, and derive corresponding hypotheses. This is followed by a description of the methodology and the results of our empirical analysis. The paper closes with discussions of findings, limitations, and implications for research and practice.

The Trajectory of IOS Migration

From Proprietary Standards to Open Standards

The phenomenon of interest in this study is firms' migration across interorganizational systems that are built on standards with relatively different degrees of openness. We start by defining key concepts. A *standard* is "a set of technical specifications adhered to by a producer, either tacitly or as a result of a formal agreement" (David and Greenstein 1990). Drawing upon this definition, we define *IOS standards* as a set of technical specifications that are agreed upon and used by IOS developers to describe data formats and communication protocols, which enable computer-to-computer communications. IOS standards differ with respect to the process of standards development and the scope of availability (David and Greenstein 1990). If a standard is developed and then available only to a closed set of firms that require a private communication platform,[4] it is considered to be a *proprietary standard*. In contrast, if a standard is developed by an open community that uses public communication platforms and software, it is considered an *open standard* (David and Greenstein 1990). As defined earlier in the "Introduction," *open-standard IOS* refers to the kind of interorganizational system that uses open standards (e.g., TCP/IP as the communication protocol, and XML or ebXML as data standards), and is built upon the open Internet for information exchange and business-to-business transactions such as sales, procurement, and customer services.[5] Based on this definition, open-standard IOS differs from earlier proprietary IOS such as the ASAP system in healthcare industry and systems such as EDI that are relatively less open.[6]

[4]The closed set of firms may include those that are members of the standards developer's community by virtue of purchase of equipment or software that is based on the standard, or by payment of a license fee. In other words, ownership of the standard belongs to the developer, thus making it proprietary. As will be discussed later, automated teller machine (ATM) networks are an example of proprietary systems.

[5]By our definition, open standards that support open-standard IOS include a hierarchy of standards at four layers: (1) physical-layer communication protocols such as TCP/IP and HTTP; (2) common standard syntax and markup languages for describing data on the Internet such as XML and other XML-based standards; (3) horizontal standards for describing products and services for interfirm coordination such as ebXML; and (4) XML-based, vertical industry standards, such as RosettaNet and Chemistry Industry Data eXchange (CIDX). See Jain and Zhao (2003) for a review of standards at these four layers.

[6]The first Analytical Systems Automated Purchasing (ASAP) system was developed by the American Hospital Supply Corporation (AHSC) in the 1960s. In 1985, AHSC was purchased by Baxter Travenol, which continued to enhance ASAP and launched several generations of ASAP systems. What this study discusses is the early ASAP platform characterized as a dedicated system with proprietary protocols (Venkatraman and Short 1992).

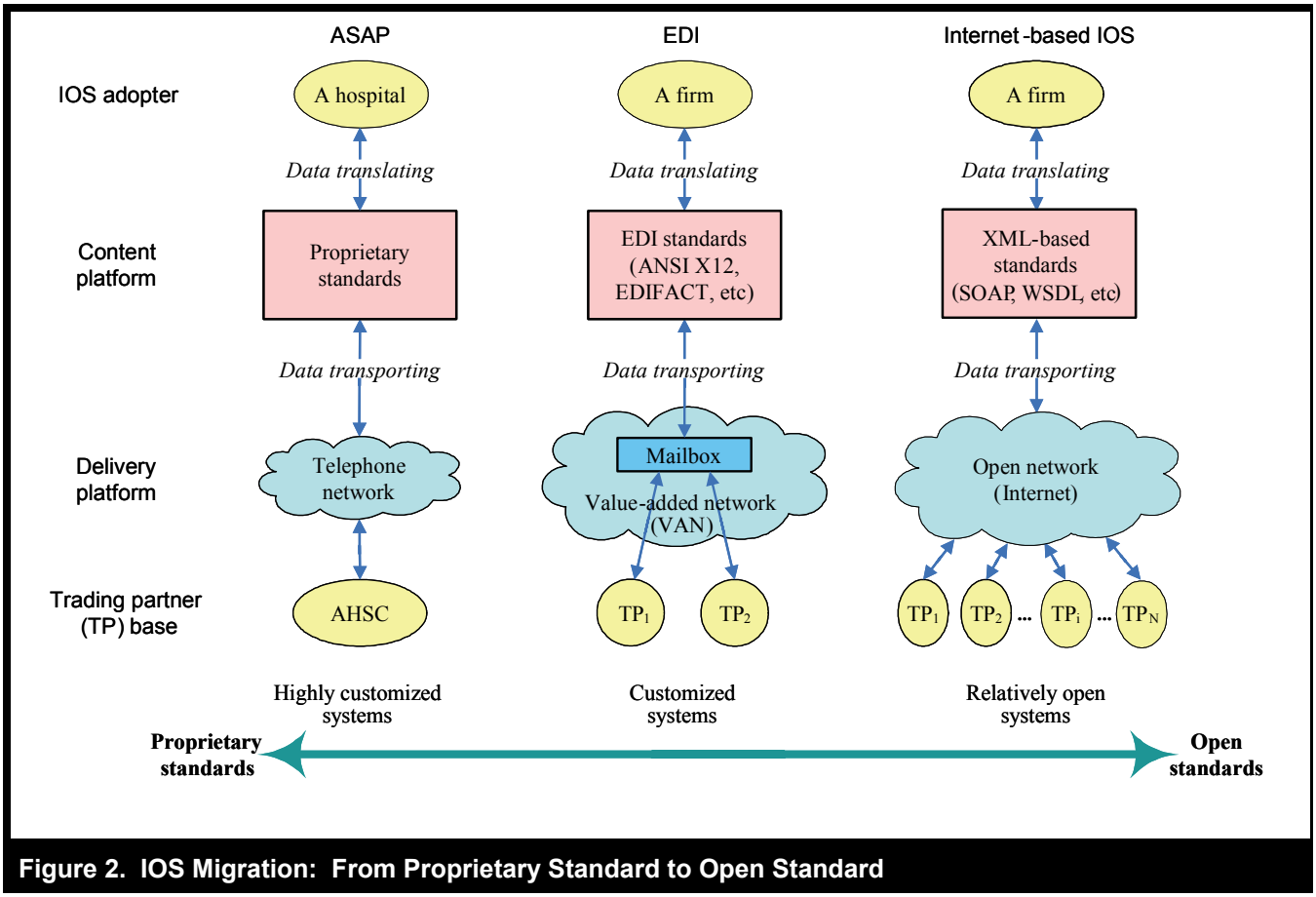

Figure 2. IOS Migration: From Proprietary Standard to Open Standard

According to the literature (Johnston and Vitale 1988), a typical IOS consists of three parts: *content platform*, *delivery platform*, and *trading partner base*. These three parts characterize the relative openness of an IOS. Using this three-part framework, we analyze the relative openness of three generations of IOS: proprietary systems (e.g., ASAP), partially open systems (e.g., EDI), and open-standard systems (Internet-based IOS). The purpose of adopting an IOS is to implement computerized communications with trading partners. Toward this end, an IOS adopter needs to have a *content platform* in place: computerized systems that translate private corporate data into a standardized data format recognizable by the IOS. Then, the standardized data are transported via a *delivery platform*: physical networks or the "pipe" used for data transmission. Finally, the data are delivered to targeted partners in the *trading partner base*. The comparison of three generations of IOS is illustrated in Figure 2.

Shown in the left column of Figure 2, the ASAP system developed by the American Hospital Supply Corporation (AHSC) for the healthcare industry is a widely cited proprietary IOS (Venkatraman and Short 1992). ASAP allowed a hospital to order supplies by using its own computers that were linked to AHSC's mainframes via a telephone network. AHSC had ultimate control over data standards, participation, and access, and also held complete responsibility for planning, developing, and managing the system (Johnston and Vitale 1988). Thus, the content platform in ASAP was built upon proprietary standards and included highly customized systems for communicating only with AHSC (Venkatraman and Short 1992). As a typical proprietary IOS, ASAP was designed to lock-in its adopters, resulting in a dedicated relationship between hospitals and their "prime vendor"—AHSC (Venkatraman and Short 1992).

EDI, as shown in the middle column of Figure 2, differs from ASAP primarily in terms of data standards and communication protocols. Two of the most widely used EDI data standards are ANSI X12 published by American National Standard Institute (ANSI) and EDIFACT published by the United Nations Center for Administration Commerce and Transport (UNCACT). Both data standards were developed

by open consortia, and thus are considered more open than earlier standards (David and Greenstein 1990). Initial EDI standards, often developed and used by an individual company (e.g., Chrysler) and its suppliers, were more proprietary. The use of open data standards lowers the asset specificity of EDI compared to proprietary IOS like ASAP, since the content platform supports communications with a larger number of firms in the trading partner base. As to the delivery platform, EDI typically uses a privately owned value-added network (VAN). Each EDI adopter subscribes to a VAN mailbox, exchanging EDI messages via the mailbox with other VAN subscribers (Emmelhainz 1993).

An Internet-based open-standard IOS is shown in the right column of Figure 2. The defining feature of open-standard IOS is the use of XML—the *de facto* standard for generating markup languages over the Internet—to form the content platform. Based on XML, the World Wide Web Consortium (W3C) has released the Simple Object Access Protocol (SOAP), which is currently supported by the majority of the computer industry for Web services messaging. W3C has also released Web Service Description Language (WSDL) for describing attributes of products and services. Having been widely accepted across a variety of industries, SOAP and WSDL, among other XML-based standards, have promoted open-standard information exchange (Shapiro and Varian 1999b). Further, the delivery platform is the Internet, a public network with global connectivity based on open TCP/IP communication protocol. Thus, Internet-based IOS are characterized by openness of *both* the content and delivery platforms. This represents a new generation of IOS that is considered substantially more open than EDI (Choudhury et al. 1998; Gurbaxani 2002).

In summary, ASAP, EDI, and the Internet-based IOS represent three generations in IOS standards evolution. As we introduced earlier, this study seeks to examine the migration from EDI to Internet-based IOS. Next we further discuss similarities and differences between these two generations of IOS.

A Comparison of EDI and Internet-Based IOS

Data standards used in EDI and Internet-based IOS differ in terms of their degree of openness, complexity, and partner-specific customization. Relative to EDI standards, XML-based standards are more likely to facilitate cross-industry coordination (Phillips and Meeker 2000). Also, EDI messages utilize rigid, complex structures to maximize information exchange efficiency, which was critical given the high communication costs when these standards were developed. Consequently, EDI standards have a complex, hard-to-learn format. Thus, the use of EDI requires special technical skills. In contrast, XML-based standards are self-describing with flexible, easy-to-learn formats (Ricker et al. 2002). Consequently, as implementing EDI with new partners requires detailed technical negotiation based on these rigid standards, EDI users often confront high degrees of partner-specific customization (Subramani 2004). In contrast, the newer Internet-based IOS require less customization, a key feature of open-standard systems (Chau and Tam 1997). These comparisons are summarized in Table 1.

Another major distinction between EDI and Internet-based IOS is their delivery platform and communication protocols: private VANs versus the TCP/IP-based public Internet. Different VANs often support different communication protocols. Some VANs charge additional fees for inter-network connection, and many networks are not interoperable with every other network (Emmelhainz 1993). Thus, the lack of interoperability is a concern for EDI users. In contrast, the Internet, as a network of interconnected networks, uses the TCP/IP open standard and a unified network addressing scheme (Mendelson 1999). These features lead to global interoperability of disparate networks that make up the Internet. The difference in communication costs is remarkable (Ricker et al. 2002). In contrast to the low costs of Internet-based communication, the high per-message costs of VANs make EDI less suitable for small- and medium-sized firms (Iacovou et al. 1995).

Mainly because of the high degree of complexity and customization, the trading partner base of EDI is relatively narrow and typically limited to large firms. In contrast, Internet-based IOS generally have a broader trading partner base (Phillips and Meeker 2000). Particularly, certain XML-based standards, for example, Universal Description Discovery and Integration Registry (UDDI) released by the Organization of the Advancement of Structured Information Standards (OASIS), enable indexing and searching for *unknown* buyers and suppliers. This is very different from EDI where electronic connections are established only with *existing* partners. Thus, Internet-based IOS facilitate the formation of a broader trading community, which in turn would have stronger *network effects* (Bakos 1998; Zhu 2004).

Theoretical Perspectives

Having discussed the different generations of IOS standards, we proceed to theoretical considerations for open-standard IOS adoption. We draw upon the economic perspective, which views the adoption decision in terms of benefits and

Table 1. EDI Versus Internet-Based IOS

	EDI	Internet-Based IOS
Content platform		
Data standards	Open standards (e.g., ANSI X12, EDIFACT), but less open than XML)	Open standards (XML-based standards, ebXML)
Complexity	High	Low
Customization	Highly partner-specific	Less partner-specific
Delivery platform		
Communication protocols	VAN (private)	Internet (open, TCP/IP-based)
Interoperability	Low	High
Communication costs	High	Low
Trading partner base		
Scope	Relatively narrow, with existing partners	Broad, with existing and new partners, hence strong network effects

costs. In order to develop our model, we describe specific characteristics of open-standard IOS that influence the benefits and costs of adoption and use. First and foremost, we need to consider *network effects*, which represent a key feature of open-standard IOS (Shapiro and Varian 1999b). Then, the notion of *path dependency* (Cohen and Levinthal 1990) motivates us to study how prior EDI experience would affect the adoption of open-standard IOS. These theoretical issues, which will be incorporated in our conceptual model, are discussed in turn below.

Network Effects

The above discussion suggests that network effect theory (Katz and Shapiro 1985, 1994; Shapiro and Varian 1999a, 1999b) is an appropriate starting point to build our theoretical base. *Network effect theory* posits that the benefits that adopters derive from a network technology are positively associated with the size of the network (Katz and Shapiro 1986). Network effects are both direct and indirect. An example of *direct* network effects is the positive impact of the number of IOS adopters on the benefits that an individual adopter can achieve by enabling the sharing of information with a larger number of partners over the IOS. An example of *indirect* network effects is the increase in compatible software and hardware solutions as the standard diffuses. The concept of network effects has been used by a number of analytical models in the literature (e.g., Riggins et al. 1994; Wang and Seidmann 1995). While these studies show that network effects theory helps improve our understanding about IOS adoption, the literature falls short of empirical testing of the theory (Kauffman et al. 2000). We summarize the limited empirical studies in Table 2. A few studies have examined issues such as the adoption of spreadsheet software (Brynjolfsson and Kemerer 1996) and the diffusion of BITNET nodes (Gurbaxani 1990), but none have focused on the important role of standards, especially in the context of Internet-based open standards.

In the limited empirical literature, the research most closely related to ours consists of a few studies on the banking industry examining organizational characteristics and market conditions that affect the diffusion of automated teller machine (ATM) networks. For example, Hannan and McDowell (1984) examined factors affecting banks' adoption of ATMs, and found that larger banks and banks operating in more concentrated local markets were more likely to adopt ATM. Saloner and Shepard (1995) argued that the benefits of adopting a particular ATM network would be positively influenced by the number of locations and the number of users it serves. Banker and Kauffman (1988) found consistent results. Extending this stream of research by incorporating the concept of shared networks, Kauffman et al. (2000) found support for the network externality hypothesis. That is, banks that can generate a larger shared network size tend to adopt ATM early.

While these studies demonstrated the usefulness of network effect theory for analyzing technology adoption, an ATM network is different from an open-standard IOS. Historically, a bank's efforts to develop its ATM network were self-

Table 2. Literature Review of Empirical Research on IS Standards

Study	Phenomenon	Theory	Methodology	Major Finding
Brynjolfsson and Kemerer 1996	Spreadsheet packages	Network effects	Hedonic regression	Consumers are willing to pay a premium for spreadsheet package with a larger installed base
Kauffman et al. 2000	ATM	Network effects	Hazard model	Banks in markets with a larger network size tend to adopt ATM earlier
Gurbaxani 1990	Computing network (BITNET)	Network effects, innovation diffusion	S-curve regression	Network effects have significantly facilitated the diffusion of BITNET
Saloner and Shepard 1995	ATM	Network effects	Hazard model	ATM adoption delays decline in the number of branches and the value of deposits
Gallaugher and Wang 2002	Web server software	Network effects	Hedonic regression	There is a positive relationship between software price and market share
Chau and Tam 1997	Open systems	Innovation diffusion	Survey, logit regression	Open systems adoption is influenced by the technological, organizational, and environmental contexts

contained, in the sense that it was based on a network built by the bank itself and used by its own customers.[7] In this regard, ATM networks were akin to EDI systems which were typically implemented by a single large buyer (supplier) that required its key suppliers (buyers) to participate in its EDI network (Mukhopadhyay and Kekre 2002) and had limited, structured functionality. It is worth pointing out that the adoption of ATM networks required close to zero investment on the part of customers. In contrast, to establish open-standard IOS, all trading partners must invest in compatible systems and provide Internet-based services to each other. Developing open-standard IOS requires joint efforts across firm boundaries, and the benefits of adopting open-standard IOS are thus contingent on the status of network adoption by other firms in the trading community (Zhu et al. 2003). Therefore, new variables reflecting the adoption status in a wide range of suppliers and trading partners are needed to address the nature of open-standard IOS. Correspondingly, the scope of network effects is likely to be quite different.

[7]This was the case for early ATM networks, but they have now become more interoperable as interfaces between the networks are installed and common standards are developed. It is still true, however, that like EDI, there are differences in the openness of the various networks. Importantly, the functionality of these networks is limited to a few well-defined and highly structured transactions (Kauffman et al. 2000).

Path Dependency

Path dependency in technology adoption (Arthur 1989; Cohen and Levinthal 1990) is another theoretical perspective relevant to the migration across different generations of IOS. From this perspective, a firm's ability and incentive to adopt a newer technology are largely a function of its level of related experience with prior technologies (Cohen and Levinthal 1990). Based on this notion, we conceptually propose the following path-dependent effects in the migration from EDI to Internet-based IOS.

First, it is likely that, when using previous generations of IOS such as EDI, firms have fostered skills for IOS implementation, and developed a deeper understanding about the economic and organizational impacts of IOS (Lyytinen and Robey 1999). Acquired primarily through learning-by-doing (Fichman and Kemerer 1997), such skills and knowledge are critical for successful adoption of new technology standards (Cohen and Levinthal 1990). Applying this perspective to our research setting, we expect two-fold effects. On the one hand, having developed technical and managerial skills for electronic IOS, firms with EDI experience may incur a lower *level* of *adoption costs* (i.e., the direct costs related to adopting Internet-based IOS such as hardware and software implementation). On the other hand, EDI users with previous IOS experience tend to understand better the true costs, including

the difficulty of process change. Consequently, the adoption behaviors of EDI users, compared to firms without EDI experience (i.e., nonusers), will be based on a more balanced consideration of costs for newer standards.

Second, the existing literature on technology standards suggests that firms may be trapped in an old standard even though a newer, superior standard is available (Farrell and Saloner 1985). In the IOS context, EDI adoption requires substantial investment in hardware, software, and training (Emmelhainz 1993; Iacovou et al. 1995); its implementation requires firms to develop special technical skills to cope with its complexity (Subramani 2004). Furthermore, EDI is generally used for long-term, dedicated interfirm linkages (Mukhopadhyay and Kekre 2002). Together, these factors may translate into *switching costs*, which in turn might inhibit firms' migration to newer standards (Beggs and Klemperer 1992; Klemperer 1987). Switching costs are different from the adoption costs discussed above in the sense that both EDI users and nonusers have adoption costs for Internet-based IOS, but EDI users confront additional switching costs. In addition, expected benefits may also be lower for EDI users than nonusers. The existence of switching costs, coupled with lower incremental value, will make EDI users more sensitive to adoption costs. This effect will be further discussed later.

Third, as suggested by prior research on IOS, strategic considerations arising from the deployment of *relationship-specific assets* play an important role in creating benefits from IOS adoption (Bakos and Brynjolfsson 1993). For instance, Subramani (2004) found that suppliers' relationship-specific investments played a significant mediating role linking EDI usage and EDI benefits. Relationship-specific assets might be a strategic component of path dependency, as suppliers may view proprietary IOS as being more conducive to the creation of relationship-specific investments in bilateral relationships (and thus enhance their benefits) than open standards.

We integrated these theoretical perspectives, especially network effects and path dependency, and developed a suitable conceptual model for open-standard IOS adoption. This model, as shown in Figure 3, and the associated hypotheses are elaborated in the next section.

The Conceptual Model and Hypothesis Development

The Conceptual Model

Consistent with our research purpose of studying the migration to open-standard IOS, we specify the *extent of open-standard IOS adoption* as the dependent variable. Drawing upon the economic perspective that views network adoption primarily in terms of benefits and costs (Zhu and Weyant 2003), we identify *expected benefits* and *adoption costs* as two key independent variables to explain open-standard IOS adoption. Further, the theoretical discussion above leads us to believe that the expected benefits from open-standard IOS are strongly influenced by network effects (Katz and Shapiro 1985). Therefore, *network effects* are posited as another independent variable that can lead to IOS adoption both directly and indirectly (via expected benefits). Finally, because we want to understand path dependency in IOS migration (Cohen and Levinthal 1990), we specify *prior use of EDI* as a moderating variable that may influence the adoption patterns of Internet IOS. Within one unified model, these variables allow us to test network effects and path dependency in the migration from EDI to open-standard IOS. The variables are discussed in turn below.

The Dependent Variable: Open-Standard IOS Adoption

In order to reflect the extent of open-standard IOS adoption, the dependent variable is conceptualized to include three interrelated dimensions: breadth, volume, and depth (Massetti and Zmud 1996). *Breadth* refers to the number of value chain activities for which a firm has adopted open-standard IOS (Porter 1985; Zhu et al. 2003). *Volume* refers to the extent (percentage) to which each of the major value chain activities has been conducted on the open-standard IOS (Chatterjee et al. 2002; Zhu and Kraemer 2005). *Depth* refers to the extent to which distinct infor mation systems are integrated by open Internet standards so that information can flow smoothly between back office systems within the company and between these systems with suppliers (Zhu and Kraemer 2002).[8] Based on the literature, we believe that these three dimensions should not be considered in isolation. Rather, they should be viewed as mutually reinforcing elements of network applications along the value chain. Thus, the three dimensions jointly provide a coherent and comprehensive representation for open-standard IOS adoption (Massetti and Zmud 1996).

[8]The literature provides support for our conceptualization. Massetti and Zmud (1996) proposed measuring EDI adoption by several interrelated facets including breadth, volume, and depth. They tested the usefulness of these dimensions via case research and found them to be a valid representation of EDI adoption.

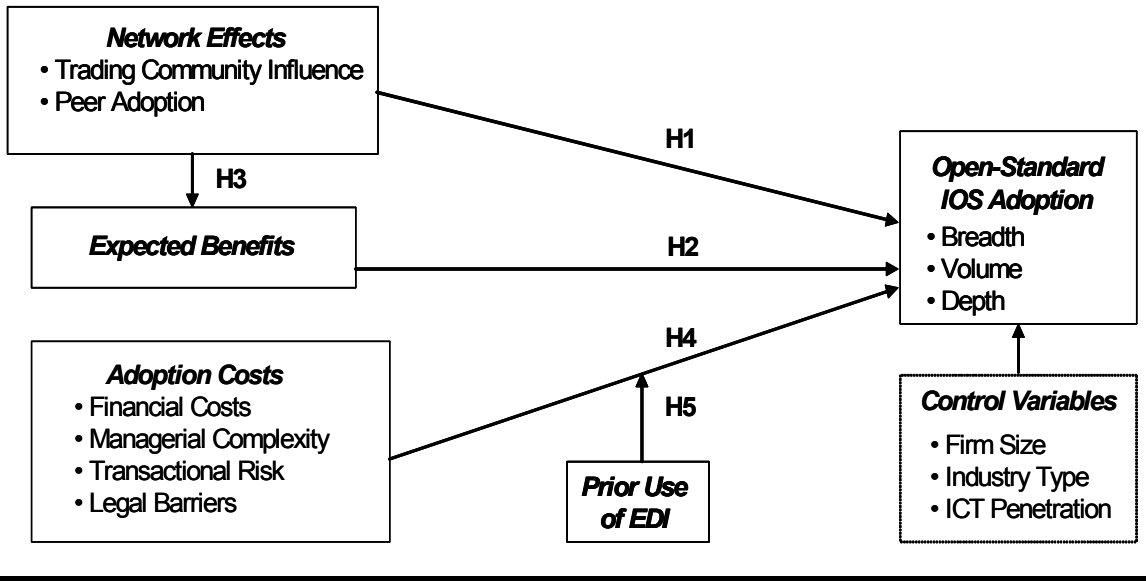

Figure 3. The Conceptual Model

The Independent Variables

Three independent variables represent the benefits and costs of adopting open-standard IOS. Below, we define these variables, identify their sub-dimensions, and explain why we have selected them.

(1) Network Effects

In the presence of *positive* network externalities (Katz and Shapiro 1985), the value of an open-standard IOS increases with its size, and thus as a network grows in size, firms will have stronger incentives to adopt it. Therefore, we propose network effects as a driver for the adoption of open-standard IOS (as represented by the top-left box in Figure 3). Furthermore, we look at factors that contribute to network effects. In doing so, it is reasonable to consider how the size of an open-standard IOS might grow.

In general, the size of an open-standard IOS network grows as two types of firms join it—vertical partners, who can be upstream or downstream in the supply chain (trading community), and horizontal peers at the same level in the supply chain (Teo et al. 2003). Thus, open-standard network effects will increase as more trading partners and peers support and adopt the open-standard IOS. We define *trading community influence* as the extent to which a firm's customers, suppliers, and other vertical partners in its trading community are willing to use or support the open-standard IOS. We define *peer adoption* as the extent of open-standard IOS diffusion among horizontal peers in the same industry. These two variables, based on the above theoretical considerations, are then specified as forming a second-order construct, *network effects*, so as to represent the construct at a higher level. Since trading community influence and peer adoption correspond to direct and indirect network effects—the two major aspects of network effects identified in the literature—our specification is consistent with the network effects literature (Farrell and Saloner 1985; Katz and Shapiro 1985).

(2) Expected Benefits

We consider a firm's expected benefits to be an important decision factor in explaining open-standard IOS adoption, which is motivated by innovation diffusion theory in which perceived benefits are an important driver of new technology adoption (Rogers 1995). *Expected benefits* refer to the operational benefits a firm expects from adopting open-standard IOS. Drawing upon the IOS literature, we further conceptualize expected benefits to include cost reduction, market expansion, and value chain coordination (Iacovou et al. 1995). First, the Internet has been widely accepted as a technology for efficient information processing, which helps firms improve operational efficiency and reduce transaction costs, search costs, and other direct and indirect costs (Zhu and Kraemer 2002, 2005). Second, firms using EDI were only

capable of exchanging information with known partners with established business relationships. Now, by using open standards, firms are able to search for and connect to unknown firms that also support open standards, facilitating expansion into new markets and reaching new customers (Phillips and Meeker 2000). Third, the open-standard Internet makes it easier for suppliers and trading partners to exchange data on inventory, delivery, and production schedules, thus improving value chain coordination (Zhu and Kraemer 2002, 2005).

Our specification is consistent with the network effects literature. Expected benefits, by our definition, go beyond the stand-alone benefits of a technology, since benefits derived via value chain coordination, market expansion, and cost reduction will be greater as network effects increase (Iacovou et al. 1995; Mukhopadhyay and Kekre 2002). Therefore, we expect strong associations among network effects, expected benefits, and open-standard IOS adoption. These relationships have been proposed or implied by theoretical research on network externalities (Farrell and Saloner 1985, 1986), although they have not been tested empirically (Kauffman et al. 2000). In particular, few studies have explicitly tested how network effects influence expected benefits, as most existing studies have proposed a direct linkage between network effects and adoption without measuring expected benefits. To better test network effects theory, it is important to incorporate the three variables in one unified model. Our proposed model, as shown in Figure 3, fills this gap by including both the direct effect (network effects→open-standard IOS adoption) and the mediated effect (network effects→expected benefits→open-standard IOS adoption).

(3) Adoption Costs

In addition to determinants of value that drive open-standard IOS adoption (i.e., network effects and expected benefits), we must also consider variables on the cost side that may hinder open-standard IOS adoption (Zhu and Weyant 2003). To identify specific cost variables, we start with *financial costs*, defined as the required financial investment in implementing and using open-standard Internet IOS (e.g., hardware and software for Internet access). Financial costs have been commonly cited as a significant factor in EDI adoption (Iacovou et al. 1995). Second, we posit *managerial complexity*, defined as the level of complexity and attendant risk associated with making process changes and the organizational adjustments necessary to accommodate the new open-standard IOS (Zhu et al. 2006a). This complexity adds significant implementation risk that can raise the overall expected costs of adoption (Chau and Tam 1997). Thus, in addition to monetary costs, complexity and its attendant risk of the change management process are considered as significant components of adoption costs. Third, we incorporate *transactional risk*, defined as risk and security concerns about transactions conducted over the Internet platform. In contrast to EDI, which has been used over several decades, the open-standard nature of the Internet IOS and its status of being a relatively new business platform bring unique issues about data security and online transactions with parties that may have no prior relationship (Zhu et al. 2006a). These factors may entail additional costs to the use of Internet-based IOS (Kraemer et al. 2006). Finally, we consider *legal barriers*, defined as the lack of institutional frameworks and business laws governing the use of Internet IOS. An immature institutional framework can substantially increase the costs of open-standard IOS in significant ways and effectively become a barrier to its diffusion (Zhu et al. 2006b).[9]

So far we have identified four variables—financial costs, managerial complexity, transactional risk, and legal barriers—as comprising adoption costs. According to a recent survey (Varian et al. 2002), these factors represent key barriers to the adoption of Internet-based IOS. In our model, they are posited as first-order variables forming adoption costs.

In summary, we have identified specific factors underlying network effects and adoption costs. There are two potential approaches to specifying their relationship with open-standard IOS adoption (Chin and Gopal 1995). The first approach views each factor as separately affecting the adoption construct. In essence, each factor is considered "a unidimensional structure that is independent of the other" (Chin and Gopal 1995, p. 49). The second approach, in contrast, treats factors underlying network effects (or adoption costs) as multidimensional entities of a higher-order construct. According to this approach, two second-order constructs, *network effects* and *adoption costs*, are postulated as "emergent constructs that are formed from the first order factors" (Chin and Gopal 1995, p. 49). The purpose of using second-order constructs is to theorize the construct at a higher level, and relate this construct to other constructs at a similar level (Rindskopf and Rose 1988).[10] Since adoption costs and network effects are constructs at a similar level and together

[9]For instance, the lack of legal protection of intellectual property on the Internet coupled with potential piracy of Internet-based initiatives, can increase the total costs to develop online initiatives (Kraemer et al. 2006).

[10]As noted by Chin (1998, p. x), "because a second order factor [construct] is modeled as being at a higher level of abstraction and reflected by first order factors, it needs to be related with other factors that are at a similar level of abstraction independent of whether these other factors are inferred from measured items or other first order factors."

they explain open-standard IOS adoption from a benefit/cost perspective, the specification of these second-order constructs is appropriate.[11]

The Moderating Variable: Prior Use of EDI

Motivated by the theoretical notion of path dependency (Cohen and Levinthal 1990), we incorporate a firm's prior experience with EDI into our model (Figure 3). As discussed earlier, firms with EDI experience tend to have gained useful insight about process changes and organizational restructuring associated with electronic IOS. On the other hand, EDI usage prior to the Internet can result in switching costs, making EDI users more *sensitive* to the costs of adopting Internet-based IOS. Thus, we expect that the effects of adoption costs will be different between firms with and without EDI experience. This line of reasoning leads us to consider EDI experience as a moderating variable that will be further discussed when we develop our hypotheses.

Control Variables

Finally, we include three control variables to account for contextual differences: *firm size*, *industry type*, and *information and telecommunication technology (ICT) penetration*. First, firm size may be positively related to innovation adoption, since large firms are more likely to possess slack resources but may be slowed down by structural inertia (Rogers 1995). Second, industry type is used to control for industry-specific differences that may affect open-standard IOS adoption, as manufacturing and service-oriented industries differ in their potential to transform value chain activities to an Internet platform (Chatterjee et al. 2002). Third, national infrastructure, especially ICT penetration, may affect the diffusion of open-standard IOS by firms (Zhu et al. 2006b). The use of these variables in our model helps control for firm-, industry-, and country-level differences that might affect open-standard IOS adoption.

Hypotheses

Network Effects

We have conceptualized two dimensions of network effects: vertical *trading community influence* and horizontal *peer adoption*. To increase the network effects of open-standard IOS, firms need to grow the participation of their suppliers, customers, and other partners in the trading community. As more trading partners adopt open-standard IOS, a firm is more likely to be part of a larger network and thereby to derive larger benefits from open standards. "Building an alliance of customers, suppliers, and complementors to support one technology over another…can be the single most important tactic [to build up the network effects]" (Shapiro and Varian 1999a, p. 32). Hence, we propose trading community influence as a significant dimension of open-standard network effects to be positively related to open-standard IOS adoption.

In addition, IOS diffusion among horizontal peers (Teo et al. 2003) may also affect the strength of network effects. As more peers adopt open-standard IOS, a larger network of IOS users will emerge, and several sources of network effects arise (Zhu 2004). First, as more peers adopt open-standard IOS, a larger market for complementary goods (including hardware and software based on compatible standards) will emerge, which will accelerate the adoption of open-standard IOS. Second, in the complementary goods market, the price will fall because of the increased competition and production scale economies, which will further drive new standards diffusion (Farrell and Saloner 1985; Katz and Shapiro 1985). These effects suggest peer adoption as another significant dimension of network effects to be positively related to open-standard IOS adoption. At a higher level, network effects, including trading community influence and peer adoption, are thus expected to drive firms' adoption of open-standard IOS. This leads to our first hypothesis:

H1: *Open-standard IOS adoption will be positively influenced by network effects.*

Expected Benefits

Expected benefits have been recognized as a major driver of innovation adoption (Rogers 1995; Tornatzky and Klein 1982). As a larger number of trading partners are connected by an open-standard IOS, network effects may induce two-way, real-time information exchange and help improve value chain coordination (Zhu 2004). Greater expected benefits in these areas will lead to more proactive adoption of the open-standard IOS (Mukhopadhyay and Kekre 2002). This argument is consistent with the innovation diffusion literature (Rogers 1995). Thus, we propose that the expected benefits would drive firms to adopt open-standard IOS, which leads to the following hypothesis:

H2: *Open-standard IOS adoption will be positively influenced by expected benefits.*

[11]We have also examined whether these second-order constructs fully mediate their respective first-order variables, and the results show that our model meets this criterion (Chin 1998).

From the above discussion, it becomes clear that expected benefits are a firm-level measure, indicating a firm's expectation of the benefits of open-standard IOS, while network effects indicate the strength of network externalities in a particular industry, which are more related to the characteristics of the industry. Yet, these expected benefits are not shaped in isolation. The strength of network effects in its industry will affect a firm's expectation about the benefits of adopting the open standard. Hence, there is a relationship between network effects and expected benefits (Kauffman et al. 2000). If a firm expects stronger network effects in its industry, it would expect higher benefits from adopting open-standard IOS, as each of the three types of benefits discussed above is subject to network externalities. In summary, network effects enabled by open standards would positively affect the firm's capabilities of cost reduction, market expansion, and value chain coordination (Zhu and Kraemer 2005). Thus, we propose the following hypothesis:

H3: *Network effects will positively influence a firm's expected benefits from the open-standard IOS.*

Adoption Costs

Adoption costs have long been posited as a barrier to the adoption of technology innovations (Tornatzky and Klein 1982). However, some researchers have argued that the higher costs could motivate firms to treat the innovation more seriously and diffuse it more actively within the organization, so as to make it cost-effective (Zaltman et al. 1973). Thus, adoption costs may also be positively correlated with the extent of IOS adoption, but this proposition has not been tested empirically. In contrast, most of the studies in the existing literature provide support for the negative effect of adoption costs (e.g., Chau and Tam 1997; Iacovou et al. 1995). We put forward the following hypothesis to test this relationship in the context of IOS adoption:

H4: *Open-standard IOS adoption will be negatively influenced by adoption costs.*

Prior Use of EDI

In line with the notion of path dependency (Cohen and Levinthal 1990), prior experience with electronic IOS may result in a deeper understanding of its costs. Consequently, when making decisions about Internet IOS adoption, EDI users would be more cognizant of the adoption costs than nonusers. This expectation is strengthened by another dimension of path dependency: the effect of switching costs (Beggs and Klemperer 1992). EDI users, although possibly having lower adoption costs in certain areas such as hardware and software, confront additional costs of switching from EDI to Internet-based IOS. EDI users have already established electronic interfirm linkages, and these linkages often involve relationship-specific investments with partners. Thus, EDI usage prior to the Internet may result in switching costs. These additional switching costs may make EDI users more *sensitive* to the adoption costs than nonusers. This leads to our final hypothesis:

H5: *The negative relationship between adoption costs and open-standard IOS adoption will be more significant for EDI users than for nonusers.*

Methodology

Data

To test the proposed model and hypotheses, we used a data set generated from a large-scale international survey designed for studying the extent of Internet adoption by firms. The survey instrument was designed on the basis of a comprehensive literature review and interviews of managers, and was refined through several rounds of pretests, revisions, and pilot tests. Each of the items on the questionnaire was reviewed by an expert panel for its content, scope, and purpose (content validity). The survey was executed via computer-aided telephone interviews by the Center for Research on Information Technology and Organizations (CRITO) in partnership with International Data Corporation (IDC) and Market Probe, two professional research firms that specialize in large-scale surveys within IT user communities in many countries.[12]

The survey was conducted in 10 economies (Brazil, China, Denmark, France, Germany, Japan, Mexico, Singapore, Taiwan, and the United States) during February, March, and April, 2002. The sample was stratified by firm size and country, with sites selected randomly within each size cell. In each country, the sample frame was obtained from a list source representative of the entire local market. Eligible respondents were those executives or managers best qualified to speak about the firm's overall computing activities. Our final data set contains 1,394 respondents. Table 3 shows the sample characteristics. Of the 1,394 respondents, 55.2 percent of firms ($N = 770$) used EDI and 44.8 percent of firms ($N = 624$) did not. The distribution of firms by size reflects a balance of large and small businesses. We tested nonresponse bias and no statistically significant differences were found. We

[12]The database is described in detail in Kraemer et al. (2006).

Table 3. Sample Characteristics (*N* = 1,394)

Category	Percent	Category	Percent
EDI Adoption		*Industry*	
EDI Users	55.2	Manufacturing	51.5
EDI Nonusers	44.8	Retail/wholesale distribution	48.5
Country (or Region)		*Number of Employees*	
Brazil	9.4	< 100	14.3
China (Mainland)	9.5	100 – 300	19.5
Denmark	9.4	300 – 500	13.6
France	9.1	500 – 1,000	15.8
Germany	9.3	1,000 – 3,000	15.4
Japan	11.1	3,000 – 5,000	5.9
Mexico	9.6	5,000 – 10,000	4.5
Singapore	9.3	> 10,000	11.0
Taiwan Province (China)	9.3		
United States	13.9		
Annual Revenue ($ million)		*Respondent Title*	
< 1	4.9	President, Managing Director, CEO	3.2
1 – 10	20.2	CIO/CTO/VP of IS	16.6
10 – 50	27.9	IS Manager, Director, Planner	35.9
50 – 100	12.4	Other Manager in IS Department	20.8
100 – 500	18.8	Business Operations Manager, COO	5.1
500 – 1000	7.2	Administration/Finance Manager, CFO	8.0
> 1000	8.6	IS Analyst, Network Administrator	4.6
		Others (Marketing VP, Other Manager)	5.8

also examined the so-called "common method bias" which can potentially occur in survey data. The results of Harman's single-factor test (Podsakoff et al. 2003) suggest that there is no significant common method bias in our data set.

Respondents in our sample include both IS and non-IS managers. One may suspect that IS managers tend to overestimate IS usage and benefits; hence we looked for the presaence of response bias in our data set due to respondents' positions. We split the full sample into two groups: IS managers (CIO, VP of IS, IS manager/director) and non-IS managers (CEO, president, COO, CFO, and other business managers). We tested whether the mean factor scores differ significantly between the two groups. Descriptive statistics and ANOVA results are shown in Appendix C. The *p*-value of the *t*-test for each variable is non-significant, indicating that respondents' positions did not result in serious biases in our data set.

Finally, our sample includes manufacturing and wholesale/retail industries, with 51.5 percent of the firms in manufacturing and 48.5 percent in wholesale/retail. These two industries deal with physical products and have widely used electronic IOS for interorganizational coordination (Mukhopadhyay et al. 1995; Subramani 2004). Evidence also suggests that firms in these two industries (e.g., Dell, Wal-Mart, and General Electric) lead in using open-standard networks to streamline transactions along the value chain (Zhu and Kraemer 2005). Thus, these two industries are appropriate testing fields for our conceptual model.

Measures

Measurement items were developed based on a comprehensive review of the literature as well as on expert opinion. We followed standard approaches to theoretical specification, statistical testing, and refinement (Straub 1989). Most constructs are operationalized by multiple items. While detailed definitions for all measurement items are shown in Appendix A, we briefly highlight the important operationalizations below.

Consistent with our earlier conceptualization, *open-standard IOS adoption* is modeled as a second-order construct reflected

by three first-order dimensions—breadth, volume, and depth. *Breadth* is measured by the number of value chain activities, for which a firm has adopted the Internet and XML-based standards. *Volume* is measured by the percentage to which each of the major value chain activities (e.g., sales, customer services, and procurement) has been conducted on the open-standard Internet platform. *Depth* is measured by the extent to which Internet standards have been integrated with back-office systems and databases, as well as with suppliers' databases (Zhu and Kraemer 2002, 2005).

Network effects are modeled as a second-order construct formed by two first-order factors: trading community influence and peer adoption. *Expected benefits* are measured by four items that reflect the potential benefits of open-standard IOS to reduce costs, expand current markets, enter new markets, and improve value chain coordination (Zhu and Kraemer 2005). Finally, *adoption costs* are modeled as a second-order construct formed by four first-order constructs: financial costs, managerial complexity, transactional risk, and legal barriers. Their definitions are provided in Appendix A.

Data Analysis and Results

We conducted data analysis using structural equation modeling (SEM) implemented in partial least squares (PLS). While several methods can be used to analyze the data, we chose PLS for two reasons. First, our model has formative constructs; PLS uses components-based algorithms and can estimate formative constructs (Chin 1998). Second, PLS is more appropriate when the research model is in an early stage of development and has not been tested extensively (Teo et al. 2003). A review of the literature suggests that empirical tests of network effects are still sparse. This work is a preliminary effort to test path dependency in the standards literature. Hence, PLS is the appropriate technique for our research purpose.

After considering the relationships of the measurement items with their respective constructs, we specified all first-order constructs as formative constructs (Chin 1998). As shown in Appendix A, all measurement items have significant ($p < 0.001$) weights with acceptable magnitude (Chin 1998). Thus, constructs measured by these items can be used for hypothesis testing. Descriptive statistics and the correlation matrix are shown in Appendix B. Results of hypothesis testing are presented below.

Full Sample

To test the hypotheses proposed earlier, we fitted our structural model on the full sample ($N = 1394$). Results are shown in Figure 4. As indicated by path loadings, both network effects ($b = 0.16$, $p < 0.001$) and expected benefits ($b = 0.27$, $p < 0.001$) have significantly positive effects on open-standard IOS adoption. This result confirms our theoretical expectation and provides support for both H1 and H2. The path from network effects to expected benefits is highly significant ($b = 0.54$, $p < 0.001$), indicating the important role of network effects in driving up the expected benefits. This provides support for H3. The path from adoption costs to open-standard IOS adoption is significant and negative ($b = -0.14$, $p < 0.001$). This is consistent with our theoretical expectation that adoption costs will inhibit open-standard IOS adoption, supporting H4.

We also examined sub-dimensions of the three second-order constructs. First, as evident from the path loadings of breadth, volume, and depth, each of these three dimensions of open-standard IOS adoption is significant ($p < 0.001$) and of high magnitude, supporting our conceptualization of the dependent construct as a second-order structure. Second, as to the factors underlying network effects, we find that trading community influence ($b = 0.79$, $p < 0.001$) is a stronger determinant of network effects than peer adoption ($b = 0.35$, $p < 0.001$), although both are significant. Third, among those factors comprising adoption costs, *managerial complexity* is shown to have the strongest impact ($b = 0.39$, $p < 0.001$). Other factors including financial costs, transactional risk, and legal barriers are found to significantly increase adoption costs ($p < 0.001$), all of which are consistent with our theoretical predictions and support our second-order conceptualization.

Finally, the three control variables have significant and positive paths to open-standard IOS adoption, suggesting that larger firms, firms in the retail/wholesale industry (as opposed to manufacturing firms), and firms in countries with higher ICT penetration are more likely to adopt open-standard IOS.[13]

[13]To examine the robustness of our results, we conducted several additional tests. First, we selected the two variables measuring trading community influence—customer support and supplier support, and dropped all firms that rated "5" on the two variables (based on a 5-point scale). This test was motivated by prior research showing that IOS adoption might be driven by mandatory requirements of a powerful buyer or supplier (Mukhopadhyay and Kekre 2002). Using the resulting sample of 1,180 firms, we fitted the structural model again and obtained consistent results. Second, we tested whether our sample includes extreme cases that would severely affect the results. We dropped firms below the 5th percentile and above the 95th percentile in terms of the three dimensions of open-standard IOS adoption. After deleting those outliers the results were still consistent with the full-sample results. Finally, to test if the significant results were driven by our large sample size, we split the full sample into two half subsamples, and obtained consistent results. These results are available from authors upon request.

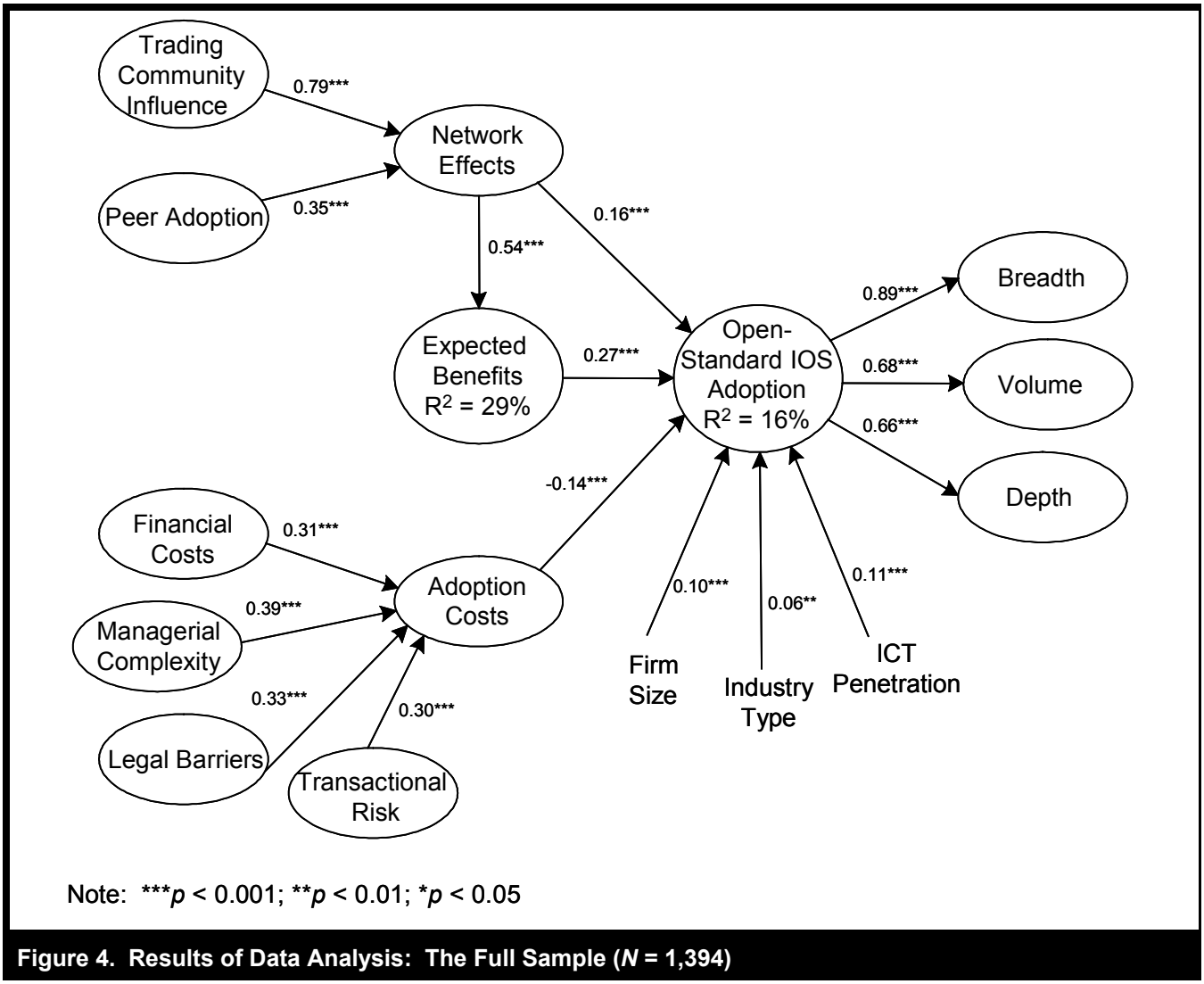

Figure 4. Results of Data Analysis: The Full Sample (*N* = 1,394)

Sample Split: EDI Users Versus Nonusers

To further compare users and nonusers of EDI in adopting open-standard IOS, we split the full sample into two subsamples, EDI users (N = 770) and nonusers (N = 624). Descriptive statistics for the two subsamples are shown in Appendix C. We then ran the structural model on the two subsamples respectively. Results are shown in Figure 5. As indicated by path estimates, the relationships of network effects and expected benefits with open-standard IOS adoption are significant and positive in both subsamples. The path from network effects to expected benefits is significant in each subsample, with a high path magnitude consistent with the full sample result. These results indicate that network effects and expected benefits drive both EDI users and nonusers to adopt open-standard IOS, and their impacts are significant and robust.

However, results shown in Figure 5 demonstrate a difference between EDI users and nonusers. We find that for EDI users, adoption costs are a significant barrier to open-standard IOS adoption (b = -0.17, $p < 0.001$); yet for nonusers, adoption costs turn out to be non-significant (b = -0.04, p = 0.58). This difference seems to support H5 wherein we propose that the negative impact of adoption costs is more significant for EDI users than for nonusers.

We further tested the differences between the two subsamples by comparing each path in the structural model for EDI users

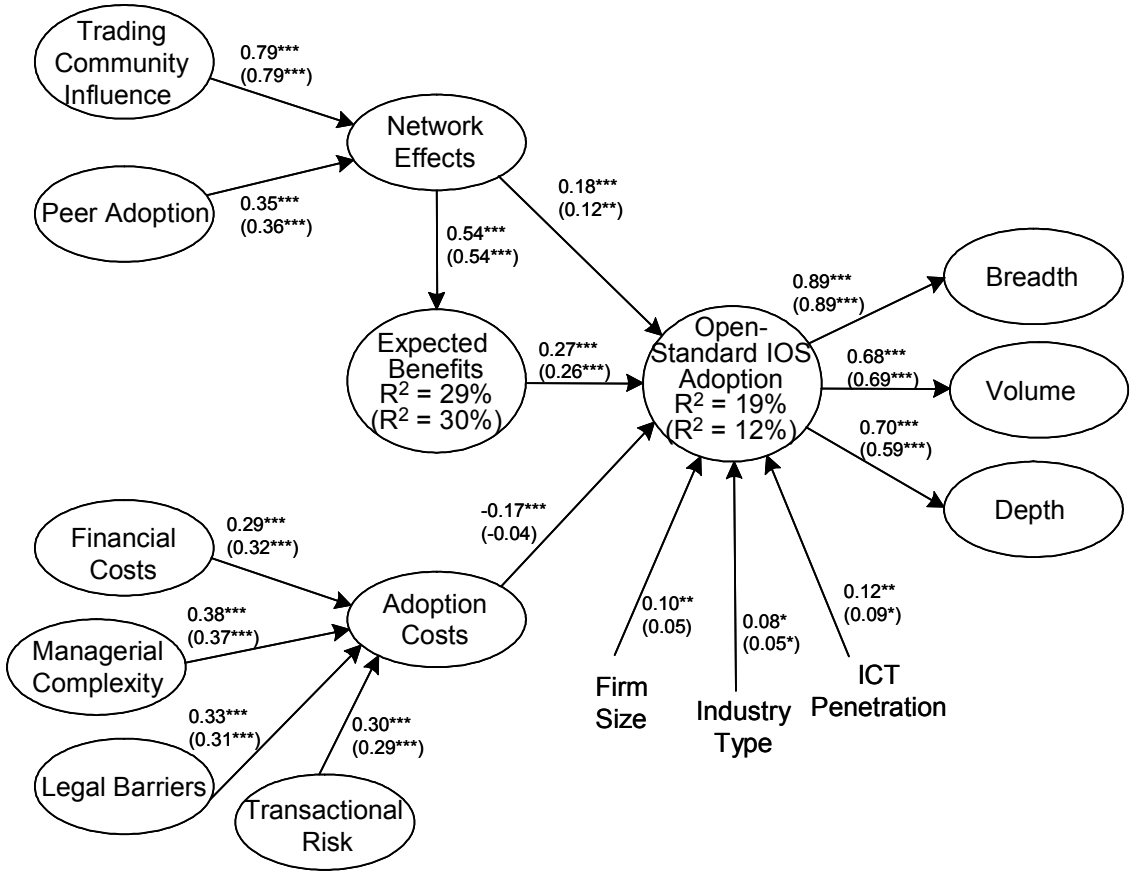

Figure 5. Results of Data Analysis: EDI Users Versus Nonusers

with the corresponding path coefficient for EDI nonusers. The significance of difference was examined by *t*-test (Venkatesh and Morris 2000). It turns out that the only path that differs significantly between the two subsamples is from adoption costs to open-standard IOS adoption ($t = 2.29$, $p < 0.05$). This result provides further support for H5. In summary, by fitting the structural model on the full sample and subsamples, we have found support for all of the five hypotheses.[14]

[14]We also studied the role of Web EDI in path dependency. With the Internet used as the "pipe" to deliver data, Web EDI still complies with EDI data standards. We added "use of Web EDI" into the model to explain adoption costs, and obtained a non-significant effect ($b = -0.02$, $p = 0.89$) with other paths remaining qualitatively unchanged. This result seems to suggest that reducing adoption costs for open-standard IOS depends more on a firm's experience in transforming data standards for business processes than simply replacing the pipe for data transportation.

Discussion

Major Findings

The empirical results of the full and split samples lead to several findings. We discuss them in two categories: network effects and path dependency.

Network Effects

First, network effects and expected benefits are significant drivers of migration to open-standard IOS. This empirical finding confirms the theoretical importance of network effects.

Our analysis of the full sample (Figure 4) assesses the significant impacts of network effects, including both direct impact

($b = 0.16$, $p < 0.001$) and indirect impact mediated through expected benefits ($b = 0.54$, $p < 0.001$; and $b = 0.27$, $p < 0.001$, respectively). The mediation relationship (network effects→expected benefits→open-standard IOS adoption) empirically confirms that the value of a network technology is positively related to the size of the network (Katz and Shapiro 1986).[15] These results, based on large-scale empirical data (Figure 4), provide empirical support for the theoretical prediction made in the network effects literature.

Second, trading community influence is a key determinant for the strength of network effects, which is consistent with the public, open-standard nature of the Internet.

To probe deeper into the determinants of open-standard network effects, we tested its underlying factors. As shown in Figure 4, *trading community influence*, with a path magnitude as high as 0.79 ($p < 0.001$), is a key determinant of the strength of network effects. This finding is consistent with the key characteristics of open-standard IOS (Shapiro and Varian 1999b). To derive network effects and realize the IOS benefits, a wide range of value chain partners, including suppliers, customers, and other trading partners, need to provide compatible services based on open standards.

Path Dependency

Third, adoption costs are a significant barrier to open-standard IOS adoption, but EDI users and nonusers treat this very differently. While EDI users are sensitive to the costs of switching to the new open-standard IOS, EDI nonusers are completely insensitive to adoption costs. This difference shows that standards migration is indeed path dependent.

The result of the sample split in Figure 5 demonstrates a difference between EDI users and nonusers: The negative influence of adoption costs on open-standard IOS adoption is significant for EDI users, but *not* significant for nonusers. A follow-up *t*-test further confirmed this difference to be statistically significant. We also tested the direct effect of EDI usage on adoption costs, which helps us better understand the role of path dependency. We specified prior use of EDI as an antecedent leading to adoption costs, and found the path to be significant and negative ($b = -0.14$, $p < 0.001$). This result suggests that prior use of EDI helps EDI users *reduce* the absolute *level* of adoption costs. It is likely that firms with EDI experience have set up data standards and communication protocols, have installed hardware and software, and have developed certain IOS technical and managerial skills (Lyytinen and Robey 1999). Thus, they may have lower adoption costs for newer technologies (Cohen and Levinthal 1990). This is consistent with path dependency in IOS migration. However, combined with the moderating effect of EDI usage on the link between perceived costs and IOS adoption (as shown in Figure 5), our results reveal an interesting paradox: *EDI user, with prior experience of using electronic IOS tend to have lower adoption costs for open-standard IOS than EDI nonusers; yet EDI users tend to be more cognizant of the costs of switching to the new open-standard IOS while EDI nonusers treat this effect very differently.*

While this may sound counterintuitive, it can be explained by the notion of *path dependency* and *organizational learning*. Adopting and implementing IOS is a process of organizational learning (Fichman and Kemerer 1997; Lyytinen and Robey 1999). Firms with EDI experience tend to gain a deeper understanding of electronic IOS about not only its benefits but also its *costs* (and the effect of the costs), especially non-obvious and intangible costs related to relationship-specific investments, standards change, process reengineering, and associated managerial complexity. As a result, they may engage in a more comprehensive analysis when assessing potential migration from EDI to open-standard IOS. In contrast, firms without any EDI experience may be driven by concerns about falling behind on the technology curve (as well as tangible benefits of moving to open-standard IOS), and thus might be eager to adopt open-standard IOS without paying sufficient attention to the costs and risks (Gurbaxani 2002).

An alternative explanation may be given from the perspective of *switching costs*. EDI users, although possibly having lower adoption costs in certain areas such as hardware and software, confront additional costs of switching from EDI to Internet-based IOS. EDI users have already established electronic interfirm linkages, and these linkages often involve relationship-specific investments with partners. Such specialized investments and entrenched relationships, along with existing data standards and electronic linkages, may translate into switching costs. Such switching costs (beyond adoption costs) would keep EDI users trapped and make them *more sensitive* to the costs of adopting open-standard IOS. Further, and also consistent with the concept of switching, the existence of a previous IOS (i.e., EDI) may bring less incremental value for EDI users and thus make them more mindful of the

[15] It is interesting to note that there is a direct network effect in addition to the mediated network effect working through expected benefits. This direct impact seems to suggest that network effects have an influence for reasons other than expected benefits; for example, there are institutional pressures that arise from the size of the network (Teo et al. 2003). Firms may be driven by bandwagon effects or competitive pressure to adopt open-standard IOS as they perceive, with an increasing number of adopters, a risk of falling behind (Abrahamson and Rosenkopf 1997).

costs of a new IOS. In contrast, EDI nonusers likely have different considerations in making adoption decisions. Observing the rapid diffusion of IOS-based interfirm coordination, EDI nonusers may view electronic IOS as having become a strategic necessity for competing with other networked firms (Hacki and Lighton 2001). Without any established IOS for interfirm coordination, they will adopt Internet-based IOS proactively, mainly driven by its low communication costs and wide trading partner base (compared to EDI). Together these effects make EDI nonusers *less sensitive* to the costs of adopting Internet-based IOS as a competitive necessity. This difference is consistent with previous "excess inertia" arguments in the literature: "competence with older technologies may offer 'traps' which make it difficult to shift to new and potentially better technologies" (Swanson 1994, p. 1082). The difference shows that prior technology paths influence the adoption of newer standards, thus indicating that IOS migration is indeed path dependent and subject to switching costs. This suggests that path dependency in standards migration is a complex and interesting research topic warranting further study.

Finally, managerial complexity is a key determinant of adoption costs.

Among the factors underlying adoption costs, *managerial complexity* is shown to be the most influential factor as indicated by its high path magnitude ($b = 0.39$, $p < 0.001$). This implies that the lack of managerial capability, instead of financial resources, to integrate the new standard into an organization's business processes represents the major difficulty for firms to migrate to open standards. The lack of managerial capability increases the risk that the needed changes will not be successfully implemented and/or will be implemented with far greater costs and fewer benefits than expected (Zhu et al. 2006a). Thus, to effectively migrate interfirm coordination to an open-standard platform, firms need to shift their attention from technical skills to managerial capabilities for organizational change and reconfiguration to function with the open standards.

Limitations and Future Research

Our methodology required tradeoffs that may limit the use of the data and interpretation of the results. Below we discuss the key limitations of this study and corresponding avenues for further research. First, this study focused on the *adoption* of open-standard IOS, but did not examine the *development* of open standards. Thus, we cannot show what factors drive standards making. It might be useful to take a process-oriented view to examine the whole process of standards development, adoption, and diffusion (David and Greenstein 1990). In the IOS setting, EDI standards and XML-based standards have been developed by industry-wide consortia, and the role of these consortia is deemed pivotal for the successful development and diffusion of IS standards. For instance, researchers have suggested studying industry-based standard-making associations to enhance the understanding about the *how* and *why* of the decision processes leading to the adoption decision (Grover 1993; Premkumar and Ramamurthy 1995). We believe further research along this line can shed new light on the whole process of standards making and subsequent diffusion among users.

Second, some factors that potentially affect migration to open-standard IOS were not available in the current data set, which limited our ability to test a more comprehensive model. Accordingly, our measures for key variables need to be refined in future data collection efforts, and additional variables should be incorporated to better measure key constructs. In particular, the following areas need refinement in further research.

First, additional research on the key dimensions of open-standard IOS migration is needed. More data should be collected to measure the scope of business processes and trading partners involved in open-standard integration. As more diversified processes, such as business-to-business selling, manufacturing and procurement, are integrated, adopters are more likely to achieve benefits from open standards (Mukhopadhyay and Kekre 2002). Second, to strengthen the network effect argument, future research should include more specific variables for measuring network effects, such as the number of IOS adopters as a percentage of major competitors (i.e., peer adoption). Research should also incorporate more detailed variables for impacts of network effects, such as the availability of compatible software in the market to reflect the effect of peer adoption (i.e., indirect network effects), and the average transaction costs in a larger network to reflect economies of scale (i.e., direct network effects). Third, future research could improve our understanding of path dependency by examining relationship-specific assets developed along the IOS migration path. For instance, EDI users may have developed business processes and domain knowledge that are specific to EDI partners; these relationship-specific assets may be strategically important for bilateral relationships, and in turn may affect the migration to open-standard IOS.

In addition, the present model (Figure 3) is based on a view that technology choices are made on the basis of economic and utility calculus in relation to different technology standards. It does not explicitly address institutional influences in IOS adoption, such as interfirm trust and exercised power.

These institutional factors were shown to be significant explanatory variables in prior research (Hart and Saunders 1997; King et al. 1994). In particular, the use of EDI may lead to dedicated buyer–supplier relationships (Mukhopadhyay and Kekre 2002). Consequently, the adoption of newer IOS by individual EDI users might depend on the decisions of the whole set of firms within the EDI relationships with the vendors and customers; in other words, they tend to move in certain "waves" (Damsgaard and Lyytinen 1998). Firms do not adopt IOS outside the relationships and commitments they have with their vendors and trading partners, and changes in IOS are evaluated in the context of the entire set of relationships and trading practices. To better explain IOS transformation, future research should add such institutional variables into our model.

Finally, the methodology presented in this paper can be applied to other technology standards with significant network effects. Good examples include the recent adoption of radio frequency identification (RFID) standards and wireless communication standards. While this study provides a basis for future research, there is clearly more work to be done.

Implications for Management

Our study results in several key insights for managers, and should help managers better understand the factors and conditions that affect the migration to open-standard IOS. Our results have highlighted the expected benefits from open standards and significant network effects as salient features of the adoption decision for open-standard IOS. Managers in firms considering adoption should assess the extent to which such technologies and standards are supported by customers, suppliers, and other business partners in the trading community. The extent of such support will substantially determine the benefits that adopters can realize. In particular, lead participants and coordinators of these trading communities must pay considerable attention to *trading community development*. This includes such activities as the provision of incentives to early adopters who are not likely to experience the benefits of network effects in the short-run, the development of common tools and databases that facilitate knowledge and information sharing to facilitate operational benefits, and implementation assistance to mitigate adoption costs.

Our study also identifies *managerial capabilities* as deserving of special attention. Adopting IOS requires considerable managerial sophistication because successful use involves not just the implemenation of new technologies but, more importantly, of new business processes that cross organizational boundaries. Thus, these systems are difficult to implement and there is substantial risk that the project might not succeed. Getting IOS implementation right is not simply a matter of providing adequate managerial time and effort, but more importantly of ensuring that the implementation team possesses the requisite capabilities in change management and project implementation. These capabilities are needed to mitigate technological implementation risk and organizational change risk, and to enhance the alignment between the technologies and organizational structure and business process. Managers should invest in the creation of organizational capital compatible with open-standard IOS, such as open organization, open communication, and organization flexibility (Brynjolfsson et al. 2002).

Firms with less IOS experience need to ensure they conduct a comprehensive analysis of the *cost-benefit equation*. As shown by our results for open-standard IOS adoption, firms without EDI experience were mainly driven by the assessment of the benefits of the new technology *per se*, and were less focused on the impact of IOS adoption costs. These firms may be quick to adopt because they are focusing on benefits, but then they will be surprised negatively by costs as they occur, and may fail to sustain their efforts.

Our study also offers implications for *policy makers*. As the diffusion of Internet technologies is hindered by institutional barriers, including inadequate legal protection for online transactions, ambiguous business laws, and security concerns, governments should establish an institutional environment that supports transactions over the open-standard IOS (Kraemer et al. 2006). This is particularly important at the early stages of open standard development in an economy (Zhu et al. 2006a). Governments could accelerate open standard diffusion by establishing supportive business and tax laws to stimulate adoption by firms (Kraemer et al. 2006). Once diffusion reaches critical mass, network effects will begin to kick in, thus speeding up diffusion and driving its assimilation in value chain activities.

Contributions to Research

This study makes several contributions to the academic literature on technology standards. First, although there are a number of theoretical studies on IOS standards, this area is lacking in terms of empirical examination of how network effects promote standards diffusion, as called for by several scholars (e.g., Brynjolfsson and Kemerer 1996; Kauffman et al. 2000). Our empirical study helps gauge the importance of *network effects* in a specific but widely used application, that is, open-standards and Internet-based IOS in a pervasive business context. The large data set (1,394 firms) increases the generalizability of the results. Our work also teases out finer-grained relationships such as the positive influence of

trading community on network effects, and the importance of managerial complexity as a key determinant of adoption costs.

Second, we considered two generations of IOS standards, and explicitly compared different pathways of network migration. We found that prior use of EDI helps reduce adoption costs for open-standard IOS adoption, yet it tends to increase switching costs in standards migration. This result provides support for the notion of *path dependency*, and has implications for research on IOS standards in general. That is, focusing on various generations in the trajectory of standards evolution might result in insights for both research and management. This seems to be an interesting undertaking: Different generations of technologies and standards tend to coexist in the market (e.g., cable networks, wireless technology, and ubiquitous systems) and firms should always evaluate the costs and benefits of migrating along different paths to incorporate changes in standards. While path dependency has been recognized as an important dimension, it has rarely been examined empirically; this study documents its considerable importance. Hence, a research design focusing on a wider scope of standards could be useful for examining standard migration.

Third, this study extends the existing literature of network technology. Compared to the existing literature on networks such as EDI and ATM, our results point to a broader scope of stakeholders that contribute to network effects. This paper focuses on an open-standard network that has broader impacts on a firm's value chain activities (compared to EDI), and examines a wider scope of partner efforts involved in establishing network effects (compared to ATM). Our conceptual model and results may have useful implications for the adoption of other types of standards such as RFID and wireless communication standards.

Finally, this study has sought to build theoretical synergy by developing a research model that incorporates theoretical perspectives of network effects, switching costs, and path dependency. Our empirical results demonstrate the usefulness of this integrative approach. Researchers have pointed out the insufficiency of relying solely on innovation diffusion theory for studying standards diffusion (Damsgaard and Lyytinen 1998); our integrative model helps address this limitation.

Concluding Remarks

As an increasing number of firms seek to improve interfirm coordination through the use of interorganizational systems, new network standards have been developed. Facing standards evolution in the marketplace, firms need to evaluate both their internal resources and external environments in order to successfully adopt new open standards. Thus, there is a growing need to understand which factors are likely to affect a firm's choices along the trajectory of standards evolution. Drawing upon the economic perspectives of network effects and path dependency, this research develops a conceptual model to examine influential factors in the migration to open-standard IOS. Unlike much of the research in the standards literature, our study goes beyond conceptualization and theorization. We have tested our conceptual model using a large and unique data set. Our empirical results gauged the significant role of network effects and adoption costs in open-standard IOS adoption, confirming the usefulness of the theoretical perspectives. We further tested underlying factors that contribute to network effects and adoption costs. We find that trading community influence is a key determinant for the strength of network effects, while managerial complexity, as opposed to financial costs, is a more significant determinant of adoption costs. Thus, it appears that the capabilities of managers in change management and technology implementation are key to successful adoption of open-standard IOS. In addition, we find that firms with and without EDI experience treat adoption costs very differently. The difference shows that prior technology paths influence the adoption of newer standards, thus suggesting that IOS migration is indeed path dependent and subject to switching costs. Experience with older standards may trap a firm and make it difficult to shift to open and potentially better standards. We hope our work will stimulate more research to further explore these issues.

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About the Authors

Kevin Zhu received his Ph.D. and Master's degrees from Stanford University. His research focuses on innovation diffusion, technology adoption and associated standards, business value of IT, information transparency in electronic markets, IT-enabled supply chains, and real options for technology investment. His research methodology involves both empirical analysis and analytical modeling. His work has been published in *Management Science*, *Information Systems Research*, *MIS Quarterly*, *Decision Sciences*, and *European Journal of Information Systems*. Along with his coauthors, he has won two Best Paper Awards of the International Conference on Information Systems (ICIS), 2002 and 2003. He recently received the prestigious CAREER Award from the U.S. National Science Foundation with a grant of $377,000 to study digital transformation of enterprises. He was the recipient of the Academic Achievement Award of Stanford University, and the Charles and Twyla Martin Excellence in Teaching Award of the University of California (voted by MBA and EMBA students).

Kenneth L. Kraemer is a professor of Information Systems and Director of the Center for Research on IT and Organizations at the Paul Merage School of Business, University of California, Irvine. His research interests include the social implications of IT, national policies for IT production and use (*Asia's Computer Challenge*, Oxford 1998), and the contributions of IT to productivity and economic development. His recent book is *Globalization of E-Commerce* (Cambridge University Press, 2006). He is starting a new study of the offshoring of knowledge work.

Vijay Gurbaxani is Associate Dean, Professor of Information Systems and Computer Science, and Director of the Center for Research on IT and Organizations Industry-University Consortium at the Paul Merage School of Business, University of California at Irvine. His research interests are in the economics of information systems. He is the author of a book, *Managing Information Systems Costs,* and numerous journal articles. His research has appeared in *Information Systems Research*, *Management Science*, and *Communications of the ACM*. Vijay Gurbaxani received Master's and Ph.D. degrees in Business Administration from the William E. Simon Graduate School of Business Administration, University of Rochester, New York, and an integrated 5-year Master's degree in Mathematics and Computer Science from the Indian Institute of Technology, Bombay. His doctoral thesis won the prize for the best dissertation in a worldwide competition sponsored by the International Center for Information Technologies. He was awarded the 2002 Outsourcing World Achievement Award in the academic category by PricewaterhouseCoopers and Michael Corbett and Associates.

Sean Xin Xu received his Ph.D. from the University of California, Irvine. His current research interests include economics of information systems diffusion, interorganizational systems and governance structure, and impacts of electronic networks on firm performance. His work has been published or accepted in *Management Science*, *MIS Quarterly*, *Journal of MIS*, and *European Journal of Information Systems*. He was the recipient, with his coauthors, of two Best Paper Awards at the International Conference on Information Systems (ICIS), 2002 and 2003, and a Best Paper Award (International Track) at the 2004 Americas Conference on Information Systems (AMCIS). He was the winner of an international doctoral research competition sponsored by SAP and the eBusiness Research Center at the Penn State University.

Appendix A

Measurement Items

Constructs and Items	Weights
Breadth—Open-Standard IOS Adoption (*Yes; No*)	
Has your firm used the Internet and XML-based standards for…	
Online procurement?	0.39***
Integrating business processes with suppliers/trading partners?	0.32***
Exchanging operational data with suppliers?	0.21***
Exchanging operational data with business customers?	0.20***
Online sales?	0.33***
Customer service and support?	0.25***
Providing product information?	0.14***
Volume—Open-Standard IOS Adoption (*Percentage*)	
Percent of total procurement ordered online	0.70***
Percent of total sales conducted online ("online" means "on the Internet")	0.59***
Percent of total customer services conducted online	0.37***
Depth—Open-Standard IOS Adoption (*5-Point Likert Scale*)	
The degree your firm has integrated the Internet and XML-based standards …	
With back office enterprise systems and databases	0.68***
With suppliers'databases	0.49***
Trading Community Influence (*5-Point Likert Scale*)	
The degree that Internet usage has been promoted by …	
Support from suppliers	0.58***
Support from customers	0.53***
Requirement in government procurement	0.33***
Peer Adoption (*5-Point Likert Scale*)	
The extent that peer companies used the Internet to conduct businesses	1.00
Expected Benefits (*5-Point Likert Scale*)	
Your firm expects the following benefits of using open-standard IOS …	
Improving coordination with suppliers/trading partners	0.28***
Expanding market for existing product/service	0.37***
Entering new business or markets	0.40***
Reducing costs	0.34***
Financial Costs (*5-point Likert Scale*)	
Costs of Internet access are high	0.54***
Costs of implementing Internet IOS are high	0.69***
Managerial Complexity (*5-point Likert Scale*)	
It is a complex and difficult task for your firm to …	
Integrate the use of the Internet IOS in the overall business process	0.53***
Make organizational changes to accommodate the Internet IOS	0.37***
Find staff with expertise of using the Internet IOS	0.46***
Legal Barriers (*5-Point Likert Scale*)	
Business laws do not support the use of the Internet	0.59***
Taxation does not support the use of the Internet	0.58***
Transactional Risk (*5-Point Likert Scale*)	
Your firm is concerned about data security and privacy on the Internet	0.41***
Online transactions are not sufficiently protected by laws (e.g., default)	0.81***
Firm Size	
Number of employees in your firm (logarithm-transformed)	1.00
Industry Type	
Is your firm in manufacturing or wholesale/retail industry?	1.00
ICT Penetration (*data source: OECD 2003*)	
Telephone mainlines per 1000 people	0.36***
Internet users per 1000 people	0.34***
PCs per 1000 people	0.36***

***$p < 0.001$. Significance test is not applicable to single-item constructs.

Appendix B

Descriptive Statistics and Correlation Matrix

			Correlation Matrix												
	Mean	**S.D.**	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) Breadth	0.75	0.49	1.00												
(2) Volume	0.14	0.19	0.44	1.00											
(3) Depth	2.80	1.28	0.38	0.24	1.00										
(4) Trading Community Influence	3.58	1.38	0.23	0.13	0.20	1.00									
(5) Peer Adoption	2.91	1.33	0.17	0.07	0.15	0.45	1.00								
(6) Expected Benefits	4.28	1.34	0.29	0.16	0.25	0.52	0.37	1.00							
(7) Financial Costs	3.00	1.24	-0.03	-0.01	0.06	0.22	0.16	0.16	1.00						
(8) Managerial Complexity	3.52	1.25	0.01	0.03	-0.03	0.23	0.24	0.17	0.50	1.00					
(9) Legal Barriers	2.77	1.29	-0.06	-0.04	0.01	0.27	0.17	0.20	0.45	0.34	1.00				
(10) Transactional Risk	3.54	1.40	-0.03	0.03	0.01	0.29	0.17	0.23	0.45	0.37	0.61	1.00			
(11) Firm Size	6.62	1.98	0.14	0.04	0.16	0.06	0.09	0.09	-0.02	0.00	-0.03	0.03	1.00		
(12) Industry Type	0.51	0.50	0.06	-0.01	0.17	0.01	0.02	0.04	0.01	-0.01	-0.01	-0.02	0.03	1.00	
(13) ICT Penetration	404.39	198.92	0.06	0.05	0.05	-0.08	0.01	-0.15	-0.01	-0.07	-0.18	-0.20	0.04	-0.02	1.00

Appendix C

Comparisons Between Different Respondents

	IS Versus Non-IS Managers						**EDI Users Versus Nonusers**					
	IS Managers		**Non-IS Managers**		**ANOVA**		**EDI Users**		**EDI Nonusers**		**ANOVA**	
	Mean	S.D	Mean	S.D.	T (*p*-value)		Mean	S.D.	Mean	S.D.	T (*p*-value)	
Breadth	0.74	0.49	0.78	0.50	1.18	(0.24)	0.83	0.49	0.66	0.47	6.47	(0.00)
Volume	0.13	0.18	0.14	0.20	0.43	(0.67)	0.15	0.19	0.11	0.18	2.99	(0.00)
Depth	2.80	1.27	2.80	1.31	0.04	(0.96)	2.92	1.23	2.63	1.33	3.84	(0.00)
Trading Community Influence	3.61	1.38	3.45	1.37	1.72	(0.09)	3.63	1.39	3.52	1.37	1.50	(0.13)
Peer Adoption	2.91	1.32	2.92	1.36	0.13	(0.89)	2.93	1.32	2.90	1.34	0.44	(0.66)
Expected Benefits	4.31	1.33	4.19	1.36	1.34	(0.18)	4.33	1.31	4.22	1.38	1.45	(0.15)
Financial Costs	2.98	1.24	3.10	1.23	1.47	(0.14)	2.85	1.15	3.19	1.31	4.95	(0.00)
Managerial Complexity	3.52	1.25	3.52	1.27	0.05	(0.96)	3.49	1.25	3.56	1.26	1.04	(0.30)
Legal Barriers	2.77	1.28	2.81	1.32	0.45	(0.66)	2.71	1.27	2.85	1.31	1.87	(0.06)
Transactional Risk	3.55	1.40	3.55	1.40	0.52	(0.61)	3.51	1.37	3.58	1.42	0.94	(0.35)