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Technology Adoption and Use Theory Review for Studying Scientists' Continued Use of Cyber-infrastructure

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ABSTRACT
In this paper, we seek to identify factors that might increase the likelihood of adoption and continued use of cyber-infrastructure by scientists. To do so, we review the main research on Information and Communications Technology (ICT) adoption and use by addressing research problems, theories and models used, findings, and limitations. We focus particularly on the individual user perspective. We categorize previous studies into two groups: Adoption research and post-adoption (continued use) research. In addition, we review studies specifically regarding cyber-infrastructure adoption and use by scientists and other special user groups. We identify the limitations of previous theories, models and research findings appearing in the literature related to our current interest in scientists' adoption and continued use of cyber-infrastructure. We synthesize the previous theories and models used for ICT adoption and use, and then we develop a theoretical framework for studying scientists' adoption and use of cyber-infrastructure. We also proposed a research design based on the research model developed. Implications for researchers and practitioners are provided.

Keywords
Cyber-infrastructure, eScience, adoption, acceptance, use

INTRODUCTION
Scientists have encountered the emergence of cyber-infrastructure or eScience as a new way to conduct their research. Cyber-infrastructure refers to the constellation of ICT that support communication, coordination, collaboration, and collection, storage, analysis and dissemination of data for distributed groups of researchers. Cyber-infrastructure holds out the promise of revolutionizing the process of scientific discovery, enabling the emergence of data-centric science—sometimes called eScience—in which researchers answer questions through the integration of distributed digital resources and facilities (Hey & Trefethen, 2008). As with the applications of technology to other kinds of work, eScience is presented as having substantial promise to reshape and enhance the way science is done. Science funding agencies are supporting development of cyber-infrastructure for various scientific communities as a way to leverage their investment in the research.

However, we believe that as with other technologies, cyber-infrastructure technologies are adopted and used less often than they are deployed. To achieve the promise of cyber-infrastructure, it is important to understand scientists' cyber-infrastructure or eScience adoption and use. Our research focuses on not only the adoption of cyber-infrastructure but also its continued use by scientists. The major research purpose of this article is to identify the main factors influencing scientists' cyber-infrastructure technology adoption and use by reviewing previous theories and models in technology adoption and use; then to develop a research model to study scientists' cyber-infrastructure adoption and use.

The main research problem in ICT adoption and use research is why and how people adopt ICTs and use them. As ICTs grow in popularity, understanding adoption and use of them is very critical in terms of design and development and deployment of new information systems and technologies. In an organizational context, the adoption and use of new ICTs has a great impact on job performance, managerial control, and organizational structure. In a non-organizational context, the adoption and use of new ICTs influence individuals' personal information management, social relationships, and quality of life. For at least 30 years, information systems scholars have sought to identify factors that influence individual users' adoption and use of ICTs.

Numerous theories and models have been proposed, as we review below. In the next sections, we provide some backgrounds regarding scientists' work environment, cyber-infrastructure technology, and ICT adoption and use in general. We also review adoption and post-adoption theories along with research issues and findings. Then, we present a research model to study scientists' cyber-infrastructure adoption and use.

BACKGROUND

Before we start, we present the research settings of scientists and the particular technologies whose adoption and use we want to study. This section is organized by scientists' work environment, cyber-infrastructure technology, and ICT adoption and use.

Scientists' Work Environment

For this paper, we are specifically interested in scientists' adoption and use of technologies that support their research, identifying factors that lead to individual decisions about what technologies to use. In taking this focus, we acknowledge that our work is more applicable to "small" rather than "big science." "Big science" refers to scientific projects that draw on multiple disciplines to address a broad set of goals, which are often set by a committee that selects the researchers to carry out the work. Big science increasingly demands eScience methods as the cost of creating knowledge has increased dramatically for many scientific ventures. In these settings, key decisions about technologies to be used are likely made at a disciplinary or organizational level.

By contrast, "small science" refers to a single investigator working on projects of their own choosing with relatively modest support, such as a graduate student or two. In small science, the advantages of eScience methods are less clear and adoption decisions are made individually, with few external factors that force adoption. In these settings, the success of cyber-infrastructure development will depend on the systems that scientists will adopt, e.g., because of their perceived usefulness for addressing problems in scientific practice or because of influences from colleagues or collaborators. This research has focused on the individual level decision on cyber-infrastructure adoption and use by scientists who are conducting "small science."

There are few studies that have been done regarding scientists' technology adoption and use, such as studies regarding specific researcher groups' ICT adoption and use. Pearce (2010) studied the technology adoption by researchers focusing on Web and eScience infrastructures to enhance research. Pearce (2010) found (1) limited evidence for disciplinary difference in tool adoption, and (2) age is negatively related to e-research tool adoption. Wiberley and Jones (2000) found that humanists are receptive to technology as long as it demonstrates adequate savings in time or effort. Dutton and Meyer (2008) found a positive attitude towards the role of e-research in terms of productivity and the use of e-research tools among social scientists. Recently, Tenopir and colleagues (2011) studied scientists' data sharing, and they found that effective data sharing and preservation are influenced by the practices and culture of the research process as well as the researchers' perceptions. However, there is as yet no overall model to guide research on adoption of cyber-infrastructure.

Cyber-infrastructure Technology

Cyber-infrastructure refers to computational and collaborative tools that support scientific work. Different terms are popular in different settings: While the U.S. National Science Foundation typically refers to cyber-infrastructure, the term eScience is more common in Europe. eScience is defined as "scholarly and scientific research activities in the virtual space generated by the networked computers and by advanced information and communication technologies" (Nentwich, 2003), to refer to the set of practices around the use of technology to support science and cyber-infrastructure for the tools and applications themselves.

eScience encompasses a broad range of distinct cyber-infrastructure applications. For many, cyber-infrastructure means high performance computing, e.g., grid computing to support simulations and analyses of large volumes of data. On a smaller scale, tools may support collection, storage, analysis, and modeling of data. Cyber-infrastructure also includes Internet-enabled applications to connect scientists to a variety of resources: Data, knowledge and collaborators. Data might come from instruments accessed remotely via the Internet, or from increasingly voluminous data repositories accessed directly or via federated searches. Scientists also use cyber-infrastructure to share data with others. eScience applications also include collaborative technologies to support scientific collaboration (Wulf, 1993), ranging from simple email and mailing lists, to newer collaborative applications such as wikis.

We conceptualize cyber-infrastructure as an assemblage of diverse technologies, as a collection of computing elements and software-based systems assembled to address an individual's diverse computing needs. For example, in writing this paper we used Google Docs, Microsoft Word, EndNote, Google Scholar and a range of library databases, a collection of articles as PDFs in various folders on a laptop, email, ManuscriptCentral, not to mention more infrastructural technologies such as the Internet, Mac OS X, Windows and laptops. The conception of an assemblage emphasizes that digitally-enabled work is increasingly done by drawing on multiple systems that are rarely well-integrated and often not formally planned, designed, delivered or governed. Our conceptualization of digital assemblages emphasizes the ad hoc and temporal nature of the elements, the importance of commercial products and commodified ICT, the impact of environmental features (e.g., a campus choice of learning management system) and the functional similarity across collections of different arrangements of digital components.

The IS literature (e.g., as reviewed below) has largely considered the 'IT artifact' as a singular technology (Carroll, 2008), though there are some exceptions. Kling and Scacchi (1982) conceptualized a computer system as an ensemble of equipments and applications, which they described as web models of technology. Lyytinen and Yoo (2002) similarly described ubiquitous computing environments as a heterogeneous assemblage of integrated socio-technical elements. Recently, scholars have also considered the adoption and use of a set of technologies (a portfolio) rather than a singular technology (Carroll, 2005, 2008). Shih and Venkatesh (2004) found that the presence of complementary technologies led to increased variety of use of the computer (Recited from Carroll 2008).

Studies of cyber-infrastructure adoption can also be informed by studies of so-called information infrastructures. Similar to our conception of a digital assemblage, Hanseth et al. (1996) described an information infrastructure as containing a huge number of interdependent components that alternate between standardization and change throughout their lifetimes. Compared to a general information system, the information infrastructure consists of diverse components whose characteristics include open, shared, evolving, socio-technical, heterogeneous (Hanseth & Monteiro, 1998). Star and Ruhleder (1996) studied the ecology of infrastructures in the particular context of a system for scientific collaboration. They emphasized the social relations of infrastructure, standards and embeddedness and considered the technology as an information infrastructure by focusing on its large, interconnected nature and installed base (Star & Ruhleder, 1996).

ICT Adoption and Use

We are focusing on ICT adoption and use research at the individual level, so our research focus excludes research on organizational technology adoption, where decisions are not made at the individual level but at organizational, division, or workgroup levels (Fichman & Kemerer, 1997; Orlikowski, 1993). Individuals' ICT adoption and use can be understood in three different stages: Pre-adoption, adoption, and post-adoption. Figure 1 shows the adoption and use processes of ICT. At the pre-adoption stage, people may examine a new technology and consider adopting it. At the adoption stage, they form an intention to adopt the technology, and they eventually purchase and use it. At the post-adoption stage, people can either continue to use the technology or abandon it. If they abandon a technology, they may start to examine another technology at the same time in order to substitute their old technology.

Figure 1. ICT Adoption Process including Pre-Adoption, Adoption, and Post-Adoption Stages

Since ICT adoption and use research is an interdisciplinary research area, it is important to develop a common vocabulary. There are several terms that need to be defined including ICT, adoption, and use. Note that we will use ICT in general in the rest of this paper, rather than Information Technology (IT) or Information Systems (IS). ICT can be defined as IT artifacts that enable people's communications and information access. ICT can include any physical devices (i.e. cell phone and cyber-infrastructure), any computer applications (e.g., Microsoft Word), or any Internet or Web services (e.g., Facebook). Adoption can be defined as a user's initial acceptance of an object. Specifically, the object here is cyber-infrastructure. The concept of "ICT use" as the post-adoption stage is employed along with ICT adoption in order to describe the continued use behavior of ICT. ICT use, originally known as IS use, can be defined as the utilization of ICT in a certain context. In the next section, we review the theories of ICT adoption and continued use (post-adoption) in order to develop a synthesized research model.

THEORY REVIEW

Theories and models in ICT adoption and use research have played a critical role. Theories and models provide frameworks to guide research design and interpret research results. Eisenhardt (1989) identifies three distinct uses of theory: As an initial guide to research design and data collection; as part of an iterative process of data collection and analysis; and as a final product of the research. Since ICT adoption and use research mainly employ positivist approach, theories and models have been used at the beginning stage of research in order to guide the research and interpret its results (Punch, 2005).

Adoption Theories

There are a good number of theories and models employed in studying individuals' ICT adoption and post-adoption behaviors. Social psychology and its applied theories and models have been mainly used in this strand of research. These theories and models focus on people's intention to engage in a certain behavior (i.e., adopt and use ICT) as a major theoretical foundation. Both Theory of Reasoned Action (TRA) and Theory of Planned Behavior (TPB) have been widely used in ICT adoption and use research. As two of the major intention based theories they provide the basic theoretical backgrounds for other adoption theories including Technology Acceptance Model (TAM) and Enhanced TAM. The basic assumption of TRA and TPB is that people consciously determine whether they engage in or do not engage in a certain behavior. In this sense, the adoption and use intentions are usually conceptualized as a major outcome variable that is influenced by various independent variables. Below we review major adoption-focused theories including TRA and TPB and their applied theories, Innovation Diffusion Theory, and Social Cognitive Theory.

Theory of Reasoned Action

As a well-known social psychology theory, Theory of Reasoned Action by Fishbein and Ajzen (1975) explains an individual's behavior based on his or her behavioral intention, which is influenced by his/her attitude toward the behavior and perception of the subjective norms regarding the behavior. TRA has been used in ICT adoption and use research as a fundamental theoretical framework, and it also has been combined with other theories and models. Both attitude and subjective norm were found to be important determinants of peoples' intentions to adopt and use ICTs (Brown, Massey, Montoya-Weiss, & Burkman, 2002; Karahanna, Straub, & Chervany, 1999). Attitude was found to have a significant influence on the intention to adopt and continue to use ICT (Anol Bhattacherjee & Premkumar, 2004; J. J. Po-An Hsieh, Rai, & Keil, 2008). Regarding the subjective norm, previous studies found that subjective norm influences not only the behavioral intention (Hu, Lin, & Chen, 2005; Venkatesh & Davis, 2000), but also other constructs including satisfaction (Hsu & Chiu, 2004), image (Chan & Lu, 2004), and perceived usefulness (Venkatesh & Davis, 2000).

Theory of Planned Behavior

Similar to TRA, Theory of Planned Behavior is a well-established social psychology theory that also states that specific salient beliefs influence behavioral intentions and subsequent behavior (Ajzen, 1991). Compared to TRA, TPB added another construct, Perceived Behavioral Control (PBC), which can be defined as "one's perceptions of his/her ability to act out a given behavior easily" (Ajzen, 1991). Many studies in ICT adoption and use research have used TPB as their theoretical framework (Hsu & Chiu, 2004; Liao, Chen, & Yen, 2007). Similar to studies using TRA, these studies also found significant relationships between attitude, subjective norm, perceived behavioral control and behavioral intention. PBC as an additional construct in TPB shed light on the importance of the perceived difficulty of the behavior and the person's perceived ability to act out the behavior. A good number of studies found that PBC directly influences the technology adoption intention (Chau & Hu, 2001; Wu & Chen, 2005) and continuance usage intention (Hsu, Yen, Chiu, & Chang, 2006; Liao, et al., 2007).

Technology Acceptance Model

The TRA and TPB have influenced the TAM and its extended models, which mainly focus on the adoption and use of ICT. Davis (1989) presented the TAM to explain the determinants of user acceptance of a wide range of end-user computing technologies. In TAM, Davis identified two theoretical constructs including Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) that affect the intention to use a system. There are a number of studies that have used TAM as their theoretical background for explaining ICT adoption and use. Scholars already confirmed that PU has a positive relationship with both adoption intention (Davis, 1989) and continuance intention (Ritu Agarwal & Karahanna, 2000; Venkatesh, 2000). In post adoption studies, PU has been found to influence satisfaction (Anol Bhattacherjee, 2001a; Moez Limayem, Hirt, & Cheung, 2007) and attitude toward the technology (Anol Bhattacherjee & Hikmet, 2008). PEOU has been found to influence both PU and adoption intention (Davis, 1989). In post-adoption studies, PEOU was found to influence satisfaction (Thong, Hong, & Tam, 2006), continuance intention (Venkatesh & Davis, 1996, 2000), and actual continuance usage (R. Agarwal, 2000; Lippert, 2007). Even though TAM was found to be a valid theoretical framework in studying ICT adoption and use, it has been criticized for its several limitations including the original model's intended generality and parsimony (Dishaw & Strong, 1999), not considering non-organizational setting (Venkatesh & Davis, 2000), and overlooking the moderating effects of ICT adoption and use in different situations (Sun & Zhang, 2006).

Enhanced Technology Acceptance Model

In order to address the limitations of TAM, Venkatesh and Davis (2000) enhanced the TAM to Extended Technology Acceptance Model (TAM2), which provides a detailed explanation of the key forces underlying judgments of perceived usefulness (Venkatesh & Davis, 2000). Using TAM as the starting point, TAM2 incorporated additional theoretical constructs including social influence processes (subjective norm, voluntaries, image, and experience) and cognitive instrumental processes (job relevance, output quality, and result demonstrability), which original TAM lacked (Venkatesh & Davis, 2000). In TAM2, the social influences such as image and subjective norm were studied in order to overcome the limitations of the original TAM. TAM2 actually incorporated social influences into an individual's perceptions of usefulness (Venkatesh & Davis, 2000). Subjective norm is the same construct that has been studied in TRA and TPB. Compared to subjective norm, image can be defined as the way that people want to be seen. Image was found to have a significant influence on perceived usefulness (Chan & Lu, 2004; Venkatesh & Davis, 2000) and attitude (Karahanna, et al., 1999). TAM2 also included diverse variables in order to enhance the explanatory power, but many times TAM2 explained low percentages of a system's use (Lu, Yao, & Yu, 2005). As TAM2 was developed in order to improve the explanatory power of the original TAM, the Unified Theory of Acceptance and Use of Technology model (UTAUT) was developed to address the same limitation in TAM2 (Venkatesh, Morris, Davis, & Davis, 2003).

Unified Theory of Acceptance and Use of Technology

UTAUT provides a refined view of how the determinants of intention and behavior evolve over time. It assumes that there are three direct determinants of intention to use (performance expectancy, effort expectancy, and social influence) and two direct determinants of usage behavior (intention and facilitating conditions) (Venkatesh, et al., 2003). These relationships are moderated by gender, age, experience, and voluntariness of use (Venkatesh, et al., 2003). Empirical testing of UTAUT shows that performance expectancy, effort expectancy, and social influence have significant relationships with the intention to use technologies (Venkatesh, et al., 2003). Later studies found that social influence affect perceived usefulness and perceived ease of use (S.-J. Hong & Tam, 2006; Lu, et al., 2005). However, in post-adoption research, social influence on the continuance intention was inconsistent; some studies reported significant relationships (S.-J. Hong & Tam, 2006; S.-J. Hong, Thong, Moon, & Tam, 2008), but other studies reported non-significant relationships (Chiu & Wang, 2008). UTAUT is one theory that covers extensive individual difference constructs including gender, age, experience, and voluntariness of use as moderating variables. Even though there are some inconsistencies in previous studies on individual differences, scholars reported significant moderating effects by individual differences such as gender (M. G. Morris, Venkatesh, & Ackerman, 2005; Venkatesh & Morris, 2000; Venkatesh, et al., 2003), age (M. Morris & Venkatesh, 2000), prior experience (Venkatesh & Davis, 1996), and voluntariness of use (Venkatesh, et al., 2003).

Innovation Diffusion Theory

Innovation Diffusion Theory (IDT) by Rogers (2003) has been employed in studying individuals' technology adoption. The main goal of IDT is to understand the adoption of innovation in terms of four elements of diffusion including innovation, time, communication channels, and social systems. IDT also states that an individual's technology adoption behavior is determined by his or her perceptions regarding the relative advantage, compatibility, complexity, trialability, and observability of the innovation, as well as social norms (Rogers, 2003). There are a number of studies that used the IDT as its theoretical framework or combined the IDT with other theories and models to explain ICT adoption and use. IS scholars mentioned that in the context of end-user computing many of the classical diffusion assertions were valid (Ritu Agarwal & Prasad, 1997; Brancheau & Wetherbe, 1990). The five main constructs of IDT were employed and found to have significant relationships with other factors in ICT adoption and use research. Relative advantage was found to have a positive relationship with attitude (Ritu Agarwal & Prasad, 2000), and relative usage intention (Lin, Chan, & Wei, 2006). Compatibility was found to influence PU (A Bhattacherjee & Hikmet, 2007), PEOU (Hernandez, Jimenez, & Martin, 2010), attitude (Ritu Agarwal & Prasad, 2000; Lee, Kozar, & Larsen, 2003), and intention (Saeed & Muthitacharoen, 2008; J.-H. Wu & Wang, 2005). Complexity was found to have a negative relationship with the technology adoption intention (Beatty, Shim, & Jones, 2001; Son & Benbasat, 2007).

Social Cognitive Theory

Social Cognitive Theory (SCT) explains how people acquire and maintain certain behavioral patterns based on the learning from others (Bandura, 1977). SCT posits that portions of an individual's knowledge acquisition can be directly related to observing others within the context of social interactions, experiences, and outside media influences. SCT suggests that behavior is affected by both outcome expectations and self-efficacy, while outcome expectations and self-efficacy are in turn influenced by prior behavior. IS scholars have used SCT and found significant relationships with other constructs in ICT adoption and use research (Compeau & Higgins, 1995a). Outcome expectations were found to influence both affect and usage (Compeau & Higgins, 1995b). Self-Efficacy was found to positively influence various adoption determinants including PEOU (Chan & Lu, 2004; Venkatesh & Davis, 1996), PU (Ritu Agarwal & Karahanna, 2000), and perceived enjoyment (Roca & Gagné, 2008). In the post-adoption research self-efficacy also influences continued intention to use a technology (Chiu & Wang, 2008; Hsu & Chiu, 2004).

Summary of Previous Theories and Models

After examining each of the seven theories and models above, we found all several similarities between the constructs used to explain individual users' technology adoption and use. Table 1 below shows how the constructs in TRA, TPB, TAM, TAM2, UTAUT, IDT, and SCT are related to each other.

Table 1. Summary of Previous Theories and Models in ICT Adoption Research

UTAUT	TRA	TPB	TAM	TAM2	IDT	SCT
Performance Expectancy	Beliefs, Attitude	Beliefs, Attitude	Perceived Usefulness	Perceived Usefulness	Relative Advantage	Outcome Expectations
Effort Expectancy		Perceived Behavioral Control	Perceived Ease of Use	Perceived Ease of Use	Complexity	Self-Efficacy
Social Influence	Subjective Norm	Subjective Norm		Subjective Norm, Image		
Facilitating Conditions				Result Demonstrability	Compatibility, Observability, Trialability	

First, "performance expectation" in UTAUT is similar to behavioral beliefs in TRA and TPB, perceived usefulness in TAM and TAM2, relative advantage in IDT, and outcome expectations in SCT. All of these constructs play a major part in explaining why people adopt and use a certain ICT. Second, many of these theories and models have the UTAUT effort expectancy construct for ICT usage that is similar to perceived ease of use in TAM, PBC in TPB, complexity in IDT, and self-efficacy in SCT. Even though all of these constructs are similar to each other, they have two distinct dimensions: Self-efficacy and controllability. Self-efficacy (internal PBC) is a construct proposed by Bandura (1986) defined as individual judgments of a person's capabilities to perform a behavior. Controllability (external PBC) is defined as individual judgments about the availability of resources and opportunities to perform the behavior (Hsu & Chiu, 2004). Third, some of these theories and models also include social influence constructs, such as subjective norm and image. Subjective norm was studied in TRA, TPB, TAM2, and UTAUT, and image was researched in TAM2, UTAUT, and IDT. Fourth, the facilitating condition construct in UTAUT appear as different types of constructs in other theories and models. For example, compatibility, observability, and trialability in IDT are related to facilitating conditions. Particularly, compatibility in IDT is associated with various beliefs including attitudinal belief (compatible with needs), normative belief (compatible with cultural and social norm), and control belief (compatible with past experience) (Rogers, 2003). Observability in IDT is also the similar to the result demonstrability, which measures the degree to which a person is able to explain to others what the device does. Trialability can be linked to experience using the device. These different constructs work as facilitating conditions in ICT adoption and use. The adoption theories and models can help us to understand the initial adoption of cyber-infrastructure by scientists.

Post Adoption Theories

Since adoption research mainly focuses on the binary condition of people's initial adoption or non-adoption, these research studies have not captured the dynamics of the post-adoption behavior of technology use. As the extension of adoption research, scholars have studied the post-adoption (use) behavior of ICTs. These studies mainly approached the post-adoption behavior as a cognitive process where people consciously examine their technologies during the usage stage. The majority of initial post-adoption studies employed the theories used in the adoption studies including TAM (Anol Bhattacherjee, 2001b; Hong, Thong, & Tam, 2006; Venkatesh, Speier, & Morris, 2002), TRA (Ahuja & Thatcher, 2005; Cenfetelli, Benbasat, & Al-Natour, 2008), and TPB (Hong, et al., 2008; Hsieh, et al., 2008; Venkatesh & Brown, 2001) for their theoretical background. These studies applied the cognitive adoption models in studying the usage behavior longitudinally. Recent post-adoption studies have applied new theoretical frameworks such as Expectation Confirmation Theory (ECT) (Anol Bhattacherjee, 2001b; Hsu, et al., 2006) and IS Continuance model (Hsieh & Wang, 2007) in order to address the changes in perceptions on technologies after people use them. These theories also reflect on people's cognitive reasoning, in regards to their post-adoption decision making processes. In addition to these cognitive process based theories and models, habit has also been explored as a factor in automatic process of technology use. In this section, we review major post-adoption-focused theories and models including ECT, IS Continuance model, and habit.

Expectation Confirmation Theory

ECT addresses the phenomenon of increasing user experiences with ICTs over a time period, which is an important consideration in studying the continued or discontinued use of technology. The ECT was originally developed by Oliver (1980) and it theorizes that consumer's post-purchase satisfaction is jointly determined by pre-purchase expectation, perceived performance (of technology), and expectancy confirmation. ECT explains the cause of satisfaction by focusing on both the antecedents of satisfaction and the satisfaction formation process (Susarla, Barua, & Whinston, 2003). There are several studies that used the ECT as a major theoretical framework in studying the post-adoption behavior of ICTs. Many of these studies found that confirmation has statistically significant relationships with various adoption and use constructs including perceived usefulness (Anol Bhattacherjee, 2001a; S. Hong, et al., 2006; J.J. Po-An Hsieh & Wang, 2007), perceived ease of use (S. Hong, et al., 2006; J.J. Po-An Hsieh & Wang, 2007; Thong, et al., 2006), perceived enjoyment (Thong, et al., 2006), perceived behavioral control (Hsu, et al., 2006), and finally satisfaction (Bhattacherjee, 2001a, 2001b; Bhattacherjee & Premkumar, 2004).

IS Continuance Model

Bhattacherjee (2001b) proposed a theoretical model of IS continuance that takes into account the distinctions between acceptance and continuance behaviors. The model is based on the similarity between individuals' continuous IS usage decisions and consumers' repeated purchase decisions by using the ECT. In both ECT and IS Continuance model satisfaction is a key concept in post-adoption behavior. In the IS field, (user) satisfaction can be defined as the affective attitude towards a particular computer application by an end user who interacts with the application directly (Doll, Hendrickson, & Deng, 1998). Smith and Bolton (2002) also argued that satisfaction represents a construct that is partly cognitive and partly emotional. IS scholars studied satisfaction as an important component of IS use (Doll, et al., 1998) and an indicator of system success (Bailey & Pearson, 1983; DeLone & McLean, 1992; Kettinger & Lee, 1994). Recently, scholars have tried to integrate user satisfaction and technology acceptance (Wixom & Todd, 2005). Studies on satisfaction found that satisfaction influences attitude toward an ICT (Anol Bhattacherjee & Premkumar, 2004) and the intention to continue using the ICT (Anol Bhattacherjee, 2001a; Moez Limayem, et al., 2007).

Habit

Habit is also studied as a major construct that influences the continued or discontinued use of technology. Across disciplines habit is commonly understood as "learned sequences of acts that become automatic responses to specific situations that may be functional in obtaining certain goals or end states" (Verplanken, Aarts, & van Knippenberg, 1997). In the context of ICT adoption and use, habit can be defined as the extent to which people tend to perform behaviors (use ICT) automatically because of learning (Moez Limayem, et al., 2007). During the initial adoption of technology, individuals are most likely involved in active cognitive processing in determining their intentions to adopt the technology. However, with any repetitive behavior occurring after the adoption of technology, reflective cognitive processing attenuates over time leading to non-reflective, routinized behavior (Ouellette & Wood, 1998). Previous post-adoption studies have ignored that frequently performed behaviors tend to become habitual and thus automatic over time (Moez Limayem, et al., 2007). Therefore, the post-adoption of technology research needs to consider not only the continuance intention but also habit. Previous post-adoption IS studies examined habit and its various determinants (S. S. Kim, 2009; Moez Limayem, et al., 2007; M.-C. Wu & Kuo, 2008). They included two antecedents of habit including frequent repetition of the behavior in question and the comprehensiveness of usage, which refers to the extent to which an individual uses the various features of the IS system in question (Moez Limayem, et al., 2007).

Limitations of Previous Theories and Research Findings

Previous ICT adoption and use research has several limitations in terms of the theories and models used and their research findings. By focusing on the adoption and use of cyber-infrastructure technologies, which is our current research interest, we inventoried the main deficiencies of previous ICT adoption and use research. First, much of previous ICT adoption and use research mainly focused on adoption as one-time event rather than investigating the evolving dynamics of ICT use after adoption. Scholars usually studied the adoption decision or intention to use a certain ICT at the initial adoption stage. These studies did not measure the actual usage behavior at the initial adoption stage as well as the continued or discontinued usage of the technology. The studies on the post-adoption behavior such as continuance and discontinuance of ICT usage would provide some alternative approaches in understanding why people continue or discontinue using a certain ICT. Similarly, many of cyber-infrastructure adoption and use studies did not actually investigate the post-adoption behavior of the technologies. Not only initial adoption but also continued use needs to be researched in studying scientists' cyber-infrastructure use.

Second, in regards to post-adoption research the previous theoretical frameworks have some limitations in terms of original theories employed and the constructs used. Previous ICT adoption and use research streams emphasized the cognitive basis for an individuals' decision about technology adoption and use. Early post-adoption research used the same theories used in adoption research. Also, the post-adoption theories and models employed similar theoretical frameworks as adoption focused theories. Also, many of post-adoption studies used constructs similar to the ones used in adoption studies to investigate the continued usage of a certain technology. Limayem et al. (2003) criticized the tendency to use the same constructs in both cross sectional and longitudinal research designs. The results from post-adoption studies using the same constructs studied in adoption research are inconsistent. For example, subjective norm is significant in the pre-adoption stage but not significant in the post-adoption stage (Hsieh, et al., 2008; M. G. Morris, et al., 2005; Roca, Chiu, & Martínez, 2006).

The third limitation of previous ICT adoption and use research is that it does not address context. Existing literature on ICT adoption and use introduces a number of different variables; however, these variables are often context-independent. ICT adoption and use research was mainly studied under organizational contexts. However, researchers can access a constantly increasing number of cyber-infrastructure technologies for their research but previous IS research often did not address the differences in contexts.

Theoretical Synthesis

Understanding various adoption and post-adoption theories and their limitations provides us with some insights to develop our own theoretical framework on the adoption and use of cyber-infrastructure by scientists. We are interested in post-adoption behavior rather than just initial adoption of cyber-infrastructure. Previous adoption studies' research models were applied in studying post-adoption behavior. Therefore, we need to develop a theoretical framework that explains and predicts continued use of cyber-infrastructure. The previous adoption and post-adoption theories and models mainly focus on the cognitive intention, but we need to expand cognitive intention into a larger research framework in order to capture different aspects of post-adoption behavior. Figure 2 below shows a possible theoretical framework that can be used to understand the post-adoption behavior of cyber-infrastructure technologies:

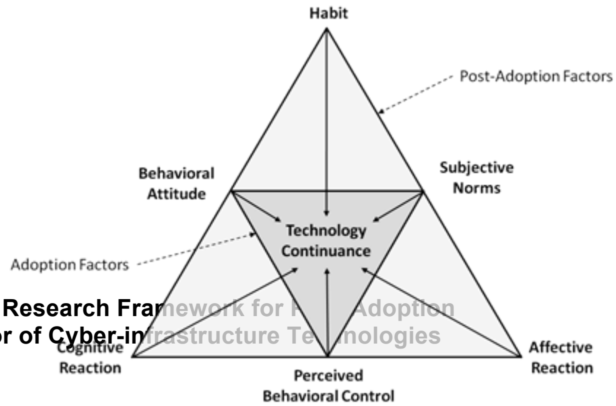

Figure 2. Research Framework for Post-Adoption Behavior of Cyber-infrastructure Technologies

The inner triangle shows previous TPB based factors affecting the intention to adopt and use a technology. The synthesis of previous theories and models indicated that people's technology adoption and use intention can be explained by three main constructs including behavioral attitude, subjective norms, and perceived behavioral control. However, this TPB based research model needs to be expanded in order to address the long-term use of technology. The proposed technology continuance model above shows three major components in studying post-adoption behavior of technology. This model still has cognitive reaction that is based on the beliefs-intention relationship, but it also includes other factors such as habit and affective reaction that are necessary to explain post-adoption behavior in using cyber-infrastructure technologies. From the post-adoption theories, we found that habit is an important factor influencing the continued use of technology.

Along with cognitive reaction and habit, affective reaction would be an important factor in continued use of cyber-infrastructure technologies because it influences satisfaction which is critical predictor for intention to continue to use a technology according to the literature. Individuals who experience pleasure or joy from using a technology and perceive any activities involving the technology to be personally enjoyable in their own right aside from the instrumental value of the technology are more likely to adopt the technology and continue to use it more extensively than others (Davis, Bagozzi, & Warshaw, 1992). Affective reaction as intrinsic motivation (Davis, et al., 1992) focuses on the satisfaction and pleasure of being involved in an activity (Deci, 1971). The affective reaction is also in line with popular definitions of emotional value, which derive from feelings and affective states that IT artifacts generate (H.-W. Kim, Chan, & Chan, 2007). Several post-adoption studies confirmed the positive relationship between affective factor and satisfaction. Since scientists would develop their satisfactions toward using cyber-infrastructure technologies, the affective reaction needs to be considered in studying scientists' cyber-infrastructure technology adoption and use.

RESEARCH DESIGN

We are in the process of designing a study to explore and test the model developed above, that we hope to deploy with the Data Observation Network for Earth (DataONE, http://dataone.org/) project. DataONE is a US National Science Foundation-supported DataNet project that is creating a set of cyber-infrastructure tools to support researchers in the environmental sciences. The project provides federated search across data repositories, plus tools for discovering, accessing, analyzing, visualizing, describing and sharing data (the "investigator's toolkit"), as well as associated resources for training and data management.

We plan to use a mixed method approach to examine researchers' assemblage adoption and use of cyber-infrastructure. During the initial stage, we will use qualitative and open-ended research approaches to expand and enrich the framework presented above. In the initial phase, we will conduct interviews and focus groups to collect factors related to the adoption and use of the cyber-infrastructure systems and assemblages. Participants for the interviews and focus groups will include those involved in trials of the systems, such as laboratory directors, researchers, engineers and research assistants. We will ask these participants to identify the different cyber-infrastructure components they use (pre- and post-cyber-infrastructure) and to describe the way they use these technologies in order to better document the variety of technological assemblages. Such a description will include the different categories of cyber-infrastructure technologies (e.g., data management tools, communication and collaboration tools and system/network technologies) and the particular systems used in each category. More importantly, we will ask participants to discuss why they decided to adopt and use the particular systems they did and their evaluation of the alternatives they considered to help surface relevant adoption and usage factors. Data will be analyzed through iterative coding, based initial on the model developed above, but with open coding to identify any emergent new factors of interest. We will use the interview and focus group data to finalize the research model, as well as to gather information about particular cyber-infrastructure technologies that would be a good focus for the next stage of the research.

In the second phase of the study, we will use a survey to examine the constructs and to test the hypothesized relationships in the research model. Given the extensive history of research on adoption and usage, we can adopt pre-tested survey items from previous studies for many constructs, perhaps with modification to make them relevant to the adoption and use of cyber-infrastructure. Necessary, new survey items will be developed. Before the actual survey, we will validate the new and modified items through a pre-test procedure with 15–20 current researchers to ensure content completeness, readability and understandability. The primary outcome measures will be adoption and usage of some of the cyber-infrastructure tools. As a number of these systems have centralized components (e.g., the federated search and data retrieval capabilities), we can measure actual usage behavior in terms of frequency and time spent rather than relying solely on self-report. The survey will be administered to cyber-infrastructure users as part of the evaluation of the project and its tools. DataONE has already conducted surveys on researchers' and librarians' attitudes towards data use and cyber-infrastructure, provide useful baseline data for comparison to our results (Tenopir, et al., 2011). Data from these surveys will be analyzed statistically to test the strength of the hypothesized relations.

DISCUSSIONS

Scientists' cyber-infrastructure technology adoption and use can be considered as two different stages including initial adoption stage and post adoption stage.

Initial Adoption Stage

As we identified in the previous sections, the initial technology adoption is determined by cognitive processes. Therefore, we need to stimulate scientists' cognitive processes in regards to their cyber-infrastructure technology adoption at the initial stage. By synthesizing previous adoption theories, we identified three main cognitive factors including performance expectancy, effort expectancy, and subjective norms. First, we think that scientists' performance expectancy toward cyber-infrastructure technologies will increase their initial adoption intention of cyber-infrastructure. The concept of performance expectancy, which is the same concept of both perceived usefulness in TAM and relative advantage in IDT, is one of critical cognitive reactions at the initial stage of cyber-infrastructure technology adoption. Second, we believe that effort expectancy toward cyber-infrastructure technologies will negatively influence scientists' initial adoption intention of cyber-infrastructure technologies. Effort expectancy is the similar concept of the perceived ease of use in TAM and complexity in IDT. For example, if scientists believe that cyber-infrastructure technologies are easy to use, then they are more likely to adoption the cyber-infrastructure technologies. Third, the subjective norm of scientists would increase their cyber-infrastructure adoption at the initial stage. Previous studies found that subjective norm is a critical factor influencing people's technology adoption at the initial stage. The peer pressure or social desirability by other scientists who use cyber-infrastructure technologies would stimulate scientists' cyber-infrastructure technology adoption at the initial stage.

As a part of cognitive reactions we need to consider a couple of facilitating conditions. We believe that three facilitating conditions including compatibility, observability, and trialability will influence both performance expectancy and effort expectancy in scientists' cyber-infrastructure adoption. First, observablity will facilitate all the three cognitive values above including performance expectancy, effort expectancy, and subjective norms. If scientists have more opportunities to see the actual cyber-infrastructure technologies, they can have a better understanding of cyber-infrastructure technologies. Also, as the observability increases, the scientists may feel more pressure than before. Second, trialability will also facilitate the two main cognitive factors: performance expectancy and effort expectancy. If scientists can actually test the cyber-infrastructure technologies before they actually adopt those technologies, they can have a better understanding of cyber-infrastructure technologies. Therefore, trialability will influence performance expectancy positively and effort expectancy negatively. Third, compatibility is an important factor in adoption decision of cyber-infrastructure technologies. Since cyber-infrastructure means the collection of different technologies, scientists will adopt a specific cyber-infrastructure technology along with their existing technologies. Therefore, the compatibility with the existing technology can positively influence scientists' cyber-infrastructure technology adoption.

Post Adoption Stage

Scientists' continued use of cyber-infrastructure technologies is more important than the initial adoption of cyber-infrastructure technologies. Even though scientists adopt cyber-infrastructure technologies at the beginning stage, they may not use the cyber-infrastructure technologies that they recently adopted. Recent IS literature has focused on the post adoption stage along with adoption stage. At the post adoption stage, we believe that the initial adoption factors focusing on cognitive reactions including performance expectancy, effort expectancy, subjective norm, and a couple of facilitating conditions. There would be two main factors including affective reaction and habit. First, we need to increase scientists' affective reaction toward cyber-infrastructure technologies. The affective reaction includes scientists' satisfactions and positive emotions. According to expectation-confirmation theory, satisfaction would be a critical construct influencing scientists' cyber-infrastructure continuance. The satisfaction regarding both performance expectancy and effort expectancy will positively influence the continued use of cyber-infrastructure technologies by scientists. In order to increase the positive relationship between expectation and confirmation in terms of performance expectancy and effort expectancy, we may need to consider some training of cyber-infrastructure technologies for scientists. Second, we need to consider how scientists make a habit in using cyber-infrastructure technologies. Across disciplines, habit is commonly understood as "learned sequences of acts that become automatic responses to specific situations, which may be functional in obtaining certain goals or end states" (Verplanken, et al., 1997).

Previous post-adoption studies have ignored that frequently performed behaviors tend to become habitual, and thus automatic over time (Moez Limayem, et al., 2007). The post-adoption of cyber-infrastructure technology research needs to consider not only the cognitive and affective reactions but also habit.

IMPLICATIONS

This research has several implications for both practitioners and researchers. In this section, we discuss some implications of this research in the perspectives of both practice and research.

For Practice

The study will provide information to guide the development and deployment of cyber-infrastructure tools. For example, knowing the relative impact of factors such as ease of use vs. usefulness will guide developers in allocating time to streamlining an interface vs. adding new functionality to a system. Understanding the importance of the previous factors vs. social norms will provide guidance for allocating resources towards broad training vs. recruiting visible lead users. Furthermore, the success of any such theory-guided interventions will provide evidence for the underlying framework. In this way, we expect our study to facilitate the adoption and use of cyber-infrastructure and the associated practices of data-intensive science, and hopefully to new scientific discovery.

We believe that cyber-infrastructure is a new way to conduct modern science and engineering research. The adoption and use of cyber-infrastructure will improve the research of science and engineering by providing better tools to manage a huge data set and facilitate collaborations. We need to consider the major adoption and continued use factors in order to improve the likelihood of adoption and continued use of cyber-infrastructure technologies. We identified both initial adoption factors and post-adoption (continued use) factors. At the initial adoption stage, we need to promote cyber-infrastructure by providing some clues about cyber-infrastructure's utility and usability values. We also need to consider some facilitating factors in order to help scientists to have more positive perception toward its utility and usability values. We believe that a demonstration session will increase the observability and trialability of cyber-infrastructure technologies; it will eventually provide scientists and engineers with better understanding of cyber-infrastructure and increase their perception toward its utility and usability values positively.

The continued use of cyber-infrastructure technologies is as important as the initial adoption. We need to consider how to motivate scientists and engineers to continue to use cyber-infrastructure technologies after their initial adoption. At the post-adoption stage, we need to have some promotion stages to maintain the perceived value of utility and usability. Since they already adopt and initially use the cyber-infrastructure technologies, some facilitating factors identified above are not important. However, we may need to increase the perceived usability, e.g., by providing an additional training session. In addition, providing some social learning opportunities may help scientists find cyber-infrastructure more interesting and useful. As scientists confirm their original expectation toward cyber-infrastructure, they will be satisfied with cyber-infrastructure, which eventually leads them to develop a good affective value. In turn, being satisfied with cyber-infrastructure should help scientists to formulate a good habit in using cyber-infrastructure.

For Research

Since cyber-infrastructure or eScience is an emerging collection of technologies, understanding its adoption and use is an important research issue. There are several research issues regarding cyber-infrastructure adoption and use. First, we may need to develop a research model in order to identify the adoption and use factors of cyber-infrastructure and their relationships. Even though we have reviewed diverse theoretical backgrounds in technology adoption and use, we need to develop our own model to address the context of cyber-infrastructure adoption and use. Once we develop our own research model, then we can test it with scientists. Second, we need to consider continued use of cyber-infrastructure as well as initial adoption of cyber-infrastructure. In order to understand the continued use of cyber-infrastructure, we need to implement a longitudinal study, which can show the post-adoption behaviors including continued use or discontinued use of cyber-infrastructure. Third, we need to develop a research framework for studying the adoption and use of assemblage of technologies. Cyber-infrastructure or eScience is not a single technology but a collection of diverse technologies. Previous studies have mainly focused the adoption and use of a single technology rather than the assemblage adoption and use of various technologies.

We need to test our research model in order to examine researchers' adoption and use of cyber-infrastructure. We can use a mixed method approach to examine the adoption and use of cyber-infrastructure by scientists. During the initial stage, we will use qualitative and open-ended research approaches to expand and enrich the framework presented above. Later, we can conduct a survey to examine the constructs and to test the hypothesized relationships in our research model. The survey results will enable us to validate our research model and understand researchers' cyber-infrastructure adoption and use. Consideration of long-term use as well as initial adoption can reveal factors related to changes in the adoption and use of cyber-infrastructure technologies and major factors influencing these changes. Of particular interest is the relative balance between cognitive, affective and habitual factors in affecting long-term use.

CONCLUSION

The main objective of this paper is to review main research problems, theories and models used, research approaches, and findings in ICT adoption and use research. Through this review, we identified the major limitations of previous theories and models, and research findings; by understanding the limitations of previous studies, we proposed some possible solutions for studying the post-adoption behavior of cyber-infrastructure technology. We developed our own theoretical framework by considering cognitive, affective, and habitual factors to study scientists' continued use of cyber-infrastructure technologies. We believe that understanding the adoption and use of cyber-infrastructure technologies is a critical research issue these days, and this research can help us to develop and deploy cyber-infrastructure in the science and engineering fields. This research paper could be the first step in understanding the main adoption and continued-use factors for scientists' and cyber-infrastructure technologies.

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