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SCOPE, LONGEVITY AND DOMAIN OF IT ARCHITECTURE, AND THEIR IMPACTS ON HOSPITAL EFFICIENCY

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Abstract

Use of information technologies in hospital has gained increased attention due to their potential to enhance efficiency and hence reduce costs and increase access. Information systems research has found complex dynamics related to IT impacts. In this research we examine how different patterns in the IT Architecture of hospitals differently impact hospital efficiency. Specifically, we examine three facets of a hospitals IT architecture: IT Architecture Spread (ITAS), IT Architecture Longevity (ITAL), and IT Architecture Domain (ITAD). Two dimensions of a hospital's IT Architecture are : IT Architecture Spread (ITAS), which refers to the breadth of digitization of hospital work processes, and IT Architecture Longevity (ITAL), which refers to the maturity of the technology portfolio implemented in a hospital. The impacts of these two dimensions are assessed across the two domains of hospitals work– clinical and business – which are referred to as IT architecture domain (ITAD). Besides the linear impacts of ITAS and ITAL we also examine their non-linear interactive impacts on hospital efficiency. Utilizing archival data on 287 Californian hospitals, our results demonstrate that the enterprise IT architectures in clinical and business domains may have significantly distinct effects on efficiency. More importantly, our research points to how the two dimensions of IT architecture can explain distinct pathways in the impacts of IT on the performance of healthcare firms.

Keywords: Healthcare, Synergies, Enterprise IT architectures, Efficiency, IT Value

Introduction

Healthcare industry is a dominant sector of economy that faces continued pressure to reduce cost and enhance efficiency. Information technologies are one of the levers through which the healthcare sector, in particular hospitals, could enhance their financial and operational performance. This intuition is evidenced in the fact that, on April 27, 2004, the government, through an Executive Order, established the position of National Coordinator for Health Information Technology with the responsibility for development, maintenance, and oversight of a strategic plan for nationwide adoption of health information technologies. However, besides the coordinated efforts in the domain of public policy and private enterprise, active contributions from researchers are needed to effectively leverage and assess the impacts of IT. While prior research suggests that information technology (IT) does enhance an organization's operational and financial performance, pathways of these impacts are found to involve intricate dynamics (Barua and Mukhopadhayay, 2000, Tanriverdi, 2006; Sambamurthy et al. 2003)1. Thus, a study of value impacts of IT use in hospitals is imperative to appropriately calibrate the expectations from IT in policy making and social analysis and debate.

Information Systems research in the last decade has ushered in an era of more in-depth and contextualized examination of IT value dynamics (Sambamurthy et al. 2003; Ray et al 2005; Rai et al. 2006). These IT value impacts have been studied at different levels. At the macro level the examination has taken into account the differences in industry, and country types (Dewan and Kraemer 2000; Mittal and Nault 2009). Organizational level analysis has looked at the different business processes such as customer service processes, (Ray et al. 2005), new product development processes (Pavlou and Sawy 2006), and supply chain and manufacturing processes (Banker et al. 2006). Another stream examines the variation in IT impacts at the level of (more aggregate) enterprise IT architecture portfolios.

Enterprise IT architectures may represent the state of information technologies and business processes in a firm. Their development and evolution has often been examined at various case sites and through theoretical postulates (Sambamurthy and Zmud 2000; Ross 2003). The notion of enterprise IT architectures has gained increased significance in the last decade, as in many instances these are found to be critical for organizational performance (Ross et al. 2006; Sambamurthy and Zmud 2000; Ross 2003; Ross and Westerman 2004). Prior studies examining value impacts of enterprise IT architectures often examine the categorization of technologies into unique types, and examine the impacts of these individual types. For example, Aral and Weill (2007) classified the overall IT investments into four different types of asset classes (Strategic, informational, transaction and infrastructure) tp examine differences in their impacts on performance of 147 U.S. firms from 1999 to 2002. Similarly, Dehning et al. (2003) examined the impacts of automate, informate and transform type IT applications on firm value. With a focus on a hospital's IT architecture, we extend this inquiry of impacts of enterprise IT architectures to the healthcare domain. Further, based on the recent conceptualization in the domain of new product development, we examine two novel dimension of a hospital's enterprise architecture - IT Architecture Spread (ITAS) and IT Architecture Longevity (ITAL), and assesses their impacts across two IT architecture domains (ITAD) within a hospital.

We use the exploration and exploitation framework to theoretically develop the relationships and examine the first research question:

Does greater spread and longevity of IT architecture have positive impact on a hospital's efficiency?

Since the two dimensions represent different patterns of IT architectures in hospitals (ITAL and ITAS), an assessment of the impacts of these dimensions suggests the likely influence of these patterns of IT architectures in a hospital. Further, we examine the second research question:

Are there positive interactive synergies (between ITAL and ITAS) that may result in a greater efficiency?

This assessment of the synergistic patterns helps examine if widely spread IT enterprise architectures with greater longevity create complementary value for a hospital. The two research questions are examined across two different domains in a hospital.

[1] Productivity paradox details

Theoretical Review

Enterprise IT applications have gained increased attention from researchers in the past few years. These architectures represent the logic of organization of a firm's IT applications across various work processes (Ross et al. 2006; Ross 2003). Enterprise IT architectures help establish long-term process-based capabilities that in turn may help enhance the performance of a firm (Ross et al. 2006). Further, these architectures evolve over time as organizations advance in learning. The differences in enterprise architectures across firms and their evolution within a firm has been a continuous theme across various research studies. For example, Ross (2003) postulated that enterprise IT architecture evolve over time across four stages- application silo architecture stage, standardized technology architecture stage, rationalized data architecture stage, and modular architecture stage. Our research focuses on these themes to develop two new dimensions of enterprise IT architectures that capture the differences in scope and longevity of IT architectures across organizations.

Researchers have emphasized various potential organizational impacts of enterprise IT architectures, such as their role in value innovation, creating IT enabled business platform, enhancing solution delivery, and enabling alliance management (Sambamurthy and Zmud 2000). Empirical assessment of these impacts on performance has primarily followed a categorization approach whereby enterprise IT applications are categorized into various types. Empirical analysis has found different impacts on value due to different types of IT systems in a firm's IT enterprise architecture (Aral and Weill 2007). Similarly, in an earlier analysis Dehning et al. (2003) conceptualized a firm's enterprise IT architecture as being automate, informate, or transform, where differential abnormal returns were found for the three different components of the IT enterprise architecture In this research, we extend this previous examination of IT enterprise architecture value by examining the patterns of overall enterprise architectures. While previous studies of enterprise architecture value have differentiated IT architectures based on the nature of IT applications, we examine two new dimensions of enterprise architectures based on the pattern of IT use. These two dimensions - ITAS and ITAL – characterize very different patterns of overall enterprises' IT architecture across organizations. Exploration and exploitation paradigm forms the basis of our conceptualization and examination of value impacts of these two dimensions.

Archival Research to assess Exploration and Exploitation Dynamics

Organization theory conceptualizes firms as a set of adaptive routines and work processes that evolve with the "exploration of new possibilities" and "exploitation of old certainties" (Schumpeter, 1934; March, 1991; Eisenhardt and Martin, 2000). According to March (1991), organizational exploration is associated with experimentation and variation within work processes, whereas exploitation is related to refinement, production, efficiency, implementation, and execution of a work process.

The concept of exploration and exploitation has been widely tested in the fields of organizational theory (Holmqvist, 2004, He and Wong, 2004), strategy (Winter and Szulanski, 2001), and managerial economics (Ghemawat and Ricart i Costa, 1993). Recognizing the multi-dimensional nature of exploration and exploitation, researchers have employed diverse methodologies including case studies, surveys, and archival data analysis to obtain better insights. Gupta et al. (2006) provide a detailed description of issues related to the definition, measurement, modeling, and interaction of exploration and exploitation in modern-day organizations. An alternate stream of research uses archival data analysis to identify the exploration and exploitation related dynamics (Katila and Ahuja, 2002, Rothaermel and Deeds, 2004). While survey-based measures offer a richer analysis, archival analysis offers a more precise and objective analysis that can be standardized across various data units. The domain of healthcare is characterized with standardized work processes and hence offers a near ideal setting for such an assessment.

Archival analysis has been used to examine product design in global robotics industry. Katila and Ahuja (2002) examined a firm's search scope and search depth as two dimensions that influence new product innovations. They examined a firm's patent citations and equate search depth - average number of times a firms used citations in the patents it applied for - to exploitation. Similarly, they examine the exploration dynamics in new product innovation through their measure of search scope defined as the proportion of previously unused citations in a firm's focal year list of citations. Similarly, Rothaermel and Deeds (2004) examine alliances between firms in biotechnology industry and assess impacts on new product development. Using an archival analysis they assess exploration alliances of a firm as a count of the total alliances that focus on the upstream activities of the biotechnology industry value chain (such as basic research, drug discovery and development). Rothaermel and Deeds examine exploitation alliances as count of total alliances that focus on downstream activities of the value chain (clinical trials, FDA regulatory process, and marketing and sales).F ollowing these applications in the domain of new product innovation we apply the conceptual distinction between exploration and exploitation toward examining differences in enterprise architectures, and their performance implications.

Based on these earlier studies, we examine the spread dimension of an enterprise IT architecture (ITAS) as analogous to the exploration of information technologies across a firm's work processes, i.e., the range of technologies adopted within a domain of work. Further, we conceptualize ITAL as an indicator of the exploitation of these technologies over time. Our conceptualization of these dimensions is very similar to that of Katila and Ahuja (2002) in the context of new product development.

IT Architectures Spread (ITAS) and IT Architectures Longevity (ITAL)

ITAS refers to the range of information technologies to digitize work processes in an organization. As work processes might vary from each other (for example, in their sensory requirements, relationship requirements, synchronism requirements, and identification and control requirements) not all of these processes may be equally valuable or suitable for digitization (Overby 2008).Variations in ITAS across firms indicates differences in organizational interests and abilities to explore the application of different information technology solutions for different work processes within a firm. Especially, in the case of healthcare firms, growth of newer information technologies to cater to varied processes has led to the availability of a wide range of information technology solutions. Similar to prior research in new innovations, ITAS is a measure of hospital's exploration of digitization possibilities by adopting information technologies across its activities (Katila and Ahuja 2002).

ITAL is the second dimension of an enterprise's IT portfolio examined in this study that helps assess the maturity of an enterprise's IT architecture. Prior research has examined how adopting organizations learn over time as to which specific features of technological solution are appropriate, how to mutually adapt the technological solution and the work domain (Leonard-Barton, 1995), and how to trigger institutional efforts to routinize the use of these technological solution within the work domain (Jasperson, Carter, and Zmud, 2005). This research concludes that it takes time and an elongated process of assimilation for the firms to realize value out of their IT investments. Over time IT architecture mature and offer new capabilities for the healthcare staff to exploit using the various information technologies. Thus, we examine the performance impact of an enterprise IT architectures longevity (ITAL) which is a critical dimension to assess the maturation effects.

The two dimensions signify very different enterprise IT architectures form within a hospital. To understand these differences, consider an example from the hospital industry. Suppose a new hospital has just recently digitized all of its business processes. This hospital has a large ITAS but limited ITAL (see Figure 1b). In contrast, another hospital that has historically been using only limited IT applications has a large ITAL with limited ITAS (see Figure 1c). We examine which of the two hospitals will realize a greater return from their enterprise IT architecture? Further, we also assess if the marginal returns to ITAS and ITAL in either of these hospitals the same as that for a hospital which has both (ITAS and ITAL) present together (see Figure 1d)?

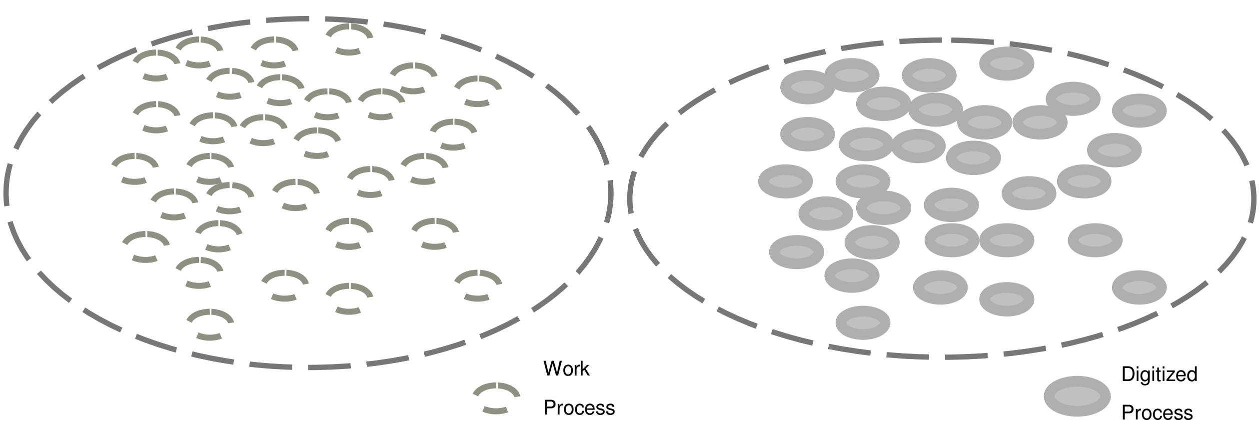

Figure 1a. Work Processes

Figure 1b. ITAS

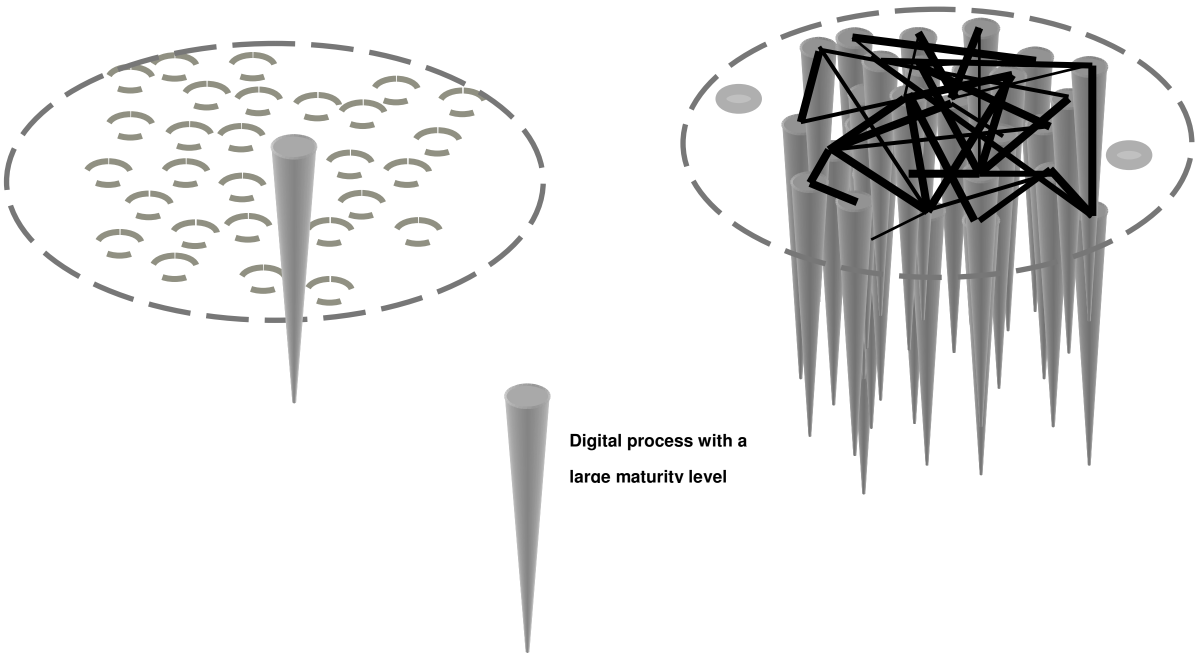

Figure 1c. ITAL　　　　Figure 1d. Synergies between ITAS and ITAL

Figure 1. Patterns of IT Enterprise Architectures

IT Architecture Domain (ITAD)

Besides differences in impacts due to ITAS and ITAL, we posit that the impacts of a hospital's IT architecture are also dependent on the domain of their application. Each domain is uniquely characterized by the set of work processes being digitized through the enterprise IT architecture (ITEA). Two domains of ITEA pertaining to healthcare are identified in this research pertaining to two different set of work processes- clinical work processes and business work processes. Clinical work processes facilitate patient treatment and coordination of medical care. Information technologies that are used within clinical domain assist medical personnel such as physicians, nurses, and pharmacists in the treatment of patients. Examples of clinical technologies include laboratory information systems, diagnostics and radiology information systems, electronic medical records, and pharmacy information systems. IT architectures in the domain of business are used to digitize work processes that help in the administration of the hospital. The business domain ITEA includes information technologies such as accounting, documentation, staff scheduling, and materials management.

ITEA for clinical domain are inherently more complex than those business domain. They deal with technologies for treatment and care of patients. Work processes in clinical activities require quick response from care providers. At the same time, a failure to consider all information can lead to fatal and costly mistakes. For example, a patient may require medication at a very short notice, however, failure to consider the interactions that the medication may have with other medications that the patient has been recently administered or failure to consider other complicating health conditions (such as diabetes or high blood pressure) can result in costly medical errors (Runy 2005). Clinical systems entail coordination of actions across multiple healthcare personnel. For example, a patient in an intensive care unit will have multiple care providers. Lack of coordination and communication among these care providers could lead to costly or even fatal errors and adverse outcomes, including costly law suits, repeat procedures, and extended length of stay for patients (Haughom 2005). Relative to clinical domain, business domain may require less coordination and the penalties for errors are less pronounced. We develop the research model (see Figure 2) and explain the rationale for each of these effects below

Research Model

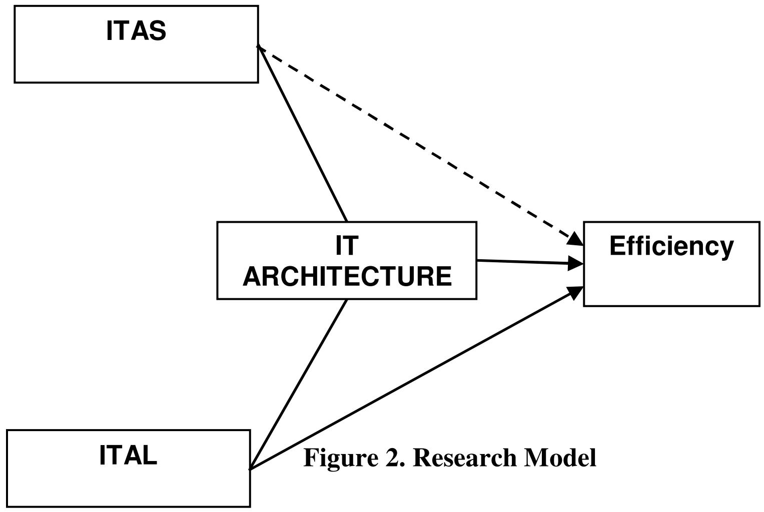

Figure 2. Research Model

Impacts of IT Architecture Longevity (ITAL) on Hospital Efficiency

ITAL captures the maturity of IT architecture. Prior research has demonstrated that at least three different organizational dynamic make ITAL an important value contributor to efficient performance. First, depending upon the nature of the technological solution, users (healthcare personnel) must make sense of its features and how to apply these in the context of their work. Users experience significant knowledge barriers in making sense of the technology and learning how to apply it effectively and efficiently. With time and experience, they are able to leverage and find faster and effective ways of using them. Second, although hospitals could enable assimilation by providing resources in the form of training, management support, or rewards and incentives, these resources themselves do not guarantee high levels of assimilation and use. Even in the presence of the enabling resources, creation of efficient work processes happens over time as users develop the needed experience and competence with the technology solutions. Finally, the efficient use of the technology requires mutual adaptations to the technology features and the work processes to which it is being applied (Leonard-Barton, 1995). Through an elongated recursive process, healthcare personnel may discover how to "fit" the features of the technology to the "adapted" tasks and activities so that the technology features are being efficiently and effectively used. As more time elapses, there is a higher probability for the mutual adaptation to occur. Purvis, Sambamurthy, and Zmud (2001) found that greater time since adoption enhances the organizational assimilation and use of information technologies. Devaraj and Kohli (2003) demonstrated that higher levels of assimilation and use are key factors in the performance impacts of information technologies. Thus, given the above arguments, with the maturation of IT architectures, hospital's employees will develop more efficient work processes. Longevity of the IT architectures thus will enable greater efficiency. More formally:

H1a: Greater longevity of IT architectures in business domain will be positively associated with greater hospital efficiency.

H1b: Greater longevity of IT architectures in clinical domain will be positively associated with greater hospital efficiency.

Impacts of IT Architecture Spread (ITAS) on Hospital Efficiency

However, the impacts of ITAS on hospital efficiency involve a much more intricate dynamics. The positive impacts of ITAS on efficiency may arise since exploration and adoption of a larger number of information technology solutions may enhance transaction processing efficiency (by influencing both speed and cost), decision-making speed and accuracy, and organizational intelligence (Huber, 1990). A greater ITAS may enhance the reach and range of work processes and help coordinate work within and across hospital boundaries at a much lower cost (Keen, 1991). Also, since information technologies are associated with lower internal and external coordination costs, a greater ITAS should lead to overall lower costs of operations (Gurbaxani and Whang, 1991). Greater clinical domain ITAS implies that a hospital has adopted a larger number of clinical applications that cumulatively would enhance the ability to gather, store, and disseminate clinical information across doctors and treatment facilities. In addition, the adoption of more clinical applications could also improve decision-making support for doctors (e.g., adverse medical interactions, prior treatment history, etc.). Greater business domain ITAS implies that technological solutions are available to support a wide range of administrative and patient relationship management activities (e.g., patient registration, billing, insurance claims). These technologies can improve the efficiency and speed of performing business activities.

While seemingly intuitive, the positive impacts of ITAS are often not automatic. Though organizations are likely to gain from a wider spread of information technologies, mere digitization may not lead to the realization of their superior capabilities (Cooper and Zmud 1990). In addition, a wider ITAS implies varied IT application adoption which may require changing existing work practices. In the case of a failure to assimilate the innovation, the hospital may be worse off as it might lose its existing set of successful routines (Mitchell and Singh, 1993). Therefore, greater experimentation with and exploration of new information systems leading to a greater ITAS may not be sufficient to warrant improvements in efficiency. Indeed, emphasizing the opinion, March (1991) points out "… returns from exploration are systematically less certain, more remote in time, and organizationally more distant from the locus of action and adaptation" (p. 73). Theoretical paradigm of exploration and exploitation offers further insights and a theoretical perspective to examine the synergies between ITAS and ITAL.

According to the paradigm, the benefits from exploration are uncertain, unless they are followed with an elongated period of exploitation. Exploration and exploitation are interactive in nature, with one supporting the other (March, 1991). While exploration helps hospital to enhance the range of options available, exploitation helps them to develop the deep expertise and experience in leveraging the performance benefits of each option. In hospitals, ITAS enhances the scope of technologies being used whereas ITAL enhances their assimilation and coordination across a set of processes in the work domain. Extended ITAS (in the absence of ITAL) leads to the adoption of disjoint technologies with little assimilation in work processes.

Together, however, ITAS and ITAL may be synergistic and mutually reinforcing. A greater ITAS implies that as new information technology solutions emerge, the adoption of a wider range of these leads to promising solutions. However, since the processes within a particular IT architecture domain are interlinked, digitization efforts must go beyond the individual process. The development of a widely digitized domain with well coordinated work processes requires both a wide range of technologies (ITAS) and an extended period to assimilate these technologies into work processes and synchronize them with each other (ITAL). This well coordinated work domain, in return, offers a technology platform that facilitates development of superior work routines to enhance the efficiency of healthcare professionals. For example, in a hospital when the physician order entry system is integrated with the emergency room records, pharmacy medication orders, laboratory information, and nursing documentation, it allows clinicians to have real-time access to data that facilitates treatment decisions (Rogoski 2006). Examples of these synergies are easily understood. For example, if laboratory and radiology processes are not as well digitized and assimilated with the operating room, the effectiveness of digitizing the operating room could be impaired. Similarly, poor communication among the care providers can lead to costly medical errors such as administering the incorrect medication or a wrong dose (Rogoski 2006). It is not just the procurement or existence of a large number of clinical technologies (a wider ITAS for clinical domain), but rather the ability of the hospital to coordinate these technologies that is the primary determinant of efficient performance (Zima 2002).

The healthcare personnel may then develop work processes that leverage this well-coordinated technology network to perform work more efficiently. As a result, we argue that ITAS and ITAL complement each other in enhancing efficiency and propose that impacts of ITAS will be positive only whey their synergies are exploited with ITAL. Thus, within both the business and clinical domains in a hospital:

H2a: Synergies between ITAS and ITAL within business domain will be positively associated with efficiency of a hospital

H2b: Synergies between ITAS and ITAL within clinical domain will be positively associated with efficiency of a hospital

Data and Methods

Data were collected from two sources – HIMSS Analytics (formerly The Dorenfest Integrated Healthcare Delivery System+ (IHDS+) database), and the Healthcare Quality and Analysis Division of the California Office of Statewide Health Planning and Development (OSHPD). HIMSS collects data on information technology usage via a survey of hospitals and maintains data for 27,000 care delivery organizations (CDO's), including 3,989 hospitals in the U.S

(Housman et al., 2006; Angst et al., 2007). HIMSS data falls into two domains of technologies according to the work processes in which they are applied – business and clinical. In our sample, twenty two technologies are categorized as business technologies and twenty seven applications cater to clinical activities[2].

To avoid biases that may arise from using the same database for measuring the dependent and independent variables, data on hospital efficiency was obtained from a different source, viz., Healthcare Quality and Analysis Division of California Office of Statewide Health Planning and Development (OSHPD). All the acute care hospitals licensed by the State of California are required to submit their annual financial reports to the OSHPD. These reports are audited before generating the annual dataset. In addition to financial information, OSHPD also reports other data, including information on ownership, size, and type of facility that are used in this research. Hospital Medicare ID was used to merge the two databases together. Our final merged sample consists of 287 observations for the year 2004.

Dependent Variable: The dependent variable, hospital efficiency, is defined as net income per patient day. Net income (NI) is a comprehensive measure of hospital performance and includes both cost and revenue performance. The efficiency of the hospital is calculated as the ratio of number of patient days (input) and net income (output). Net Income data were obtained from the OSHPD database.

Independent Variables: We use the HIMSS database to operationalize ITAS and ITAL. ITAS is defined as the number of technological solutions adopted and used by each hospital, whereas ITAL is defined as years of experience with each of these solutions. The HIMSS database provides information on a variety of tasks and processes within the business and clinical domains and details a list of technological solutions for each process within those work domains. Further, for each hospital, the database lists the specific technology solutions that they were using and the year when that solution was initially adopted. We used the count of these technology solutions as a measure of ITAS within each work domain. Further, on the basis of the year of adoption, we computed ITAL as the average number of years of use of each solution till 2004.

Computation of IT Architecture Spread (ITAS): If kihθ ε (0,1) indicates whether the information technology i was adopted by the business process b in the work domain θ in the hospital h, then ITAS is measured as the ratio:

$$ITAS_{\theta h} = \sum_{i=1}^{M} \sum_{i=1}^{N} k_{ib\theta h},,$$

where M represents the number of business process available for the work domain θ, and N is the number of technologies that support the work processes in a domain θ. For business systems, the work processes being studied in this research includes human resource and financial management, etc. Since information technologies include a wide range of features and functionalities coded into them, $ITAS_{\theta h}$ measures the extent to which a particular hospital has explored its technology options to digitize work processes.

Computation of IT Architecture Longevity (ITAL): ITAL with the adopted information technologies is computed as:

$$ITAL_{\theta h}{}^{3} = 1/M \sum_{i=1}^{M} \cdot \left[\frac{\sum_{i-1}^{N} Y_{ib\theta h} K_{ib\theta h}}{\sum_{i=1}^{N} K_{ib\theta h}} \right]$$

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[2] A complete list of technologies available from authors upon request

[3]The form of average experience gives equal weight to each type of business function (e.g. HR, or Financial management) in an activity system. Hence it is robust to the larger numbers that might be needed for a function (even though their impact on efficiency may not be proportional). Also, the formulation controls for any missing data that might distort the results across hospitals. Further, the robustness of results against any missing data was tested by dropping these missing observations and the results are qualitatively unchanged.

Where, Yibθh represents the experience or the number of years that a hospital h has used the information technology i in the work process b of its domain θ. $ITAL_{\theta h}$ measures the overall average experience with all information technologies in the work domain θ.

Synergies (αθh) Computation: Complementarities are measured as the product (interaction) of $ITAS_{\theta h}$ and $ITAL_{\theta h}$. Further, we do an in-depth assessment of synergies between ITAS and ITAL by developing three unique ratios – Overall Architecture Growth to Spread (AGS), Overall Architecture Growth to Longevity (AGL), and Architecture Growth across Domains (AGD). The recent development in IS literature assessing IT complementarities forms the basis for the development of these ratios. If ITAS and ITAL represent spread and longevity of IT architecture, Effeciency is a a function of the two and their joint synergies $\alpha_{h\theta}$,i.e. $E_h= f(ITAS_{bh}, ITAL_{bh}, ITAS_{ch}, ITAL_{ch}, \alpha_{bh}, \alpha_{ch})$. The joint synergies ($\alpha_{h\theta}$) assesses the relative impact of ITAS in presence of ITAL (or vice versa), and according to recent conceptualizations may be represented as $\frac{\partial^2 E}{\partial \mathrm{ITAS}_\theta \partial \mathrm{ITAL}_\theta}$ (Milgrom and Roberts 1990, 1995, Tanriverdi and Lee 2008; Siggelkow 2002).

Based on this conceptualization AGS, and AGL are defined as the ratio of the synergistic impacts (second order cross partial derivative) to the direct effects (the first order derivative) of efficiency with respect to spread and longevity of IT architecture respectively. The two ratios – AGS and AGL – may be evaluated in two domains of healthcare (business and clinical). Thus, for example, the business domain architecture growth to spread ratio (AGS) evaluates the strength of synergistic impact with respect to spread of business IT architecture portfolio. A value greater than 1 for the AGS or AGL implies that synergistic impact has a stronger influence on efficiency than the direct impact of spread or longevity.

i. whether $AGS_b = \left|\frac{\partial^2 E}{\partial \mathrm{ITAS_b} \partial \mathrm{ITAL}_b}\right| \Big/ \left|\frac{\partial E}{\partial ITAS_b}\right| \geq 1$. A similar interpretation can be made for AGL> 1

ii. whether $AGL_b = \left|\frac{\partial^2 E}{\partial \mathrm{ITAS_b} \partial \mathrm{ITAL}_b}\right| \Big/ \left|\frac{\partial E}{\partial ITAL_b}\right| \geq 1$.

AGS and AGL offer valuable managerial information to assess and manage impacts of IT architecture. For example, $\frac{\partial^2 E}{\partial \mathrm{ITAS}_\theta \partial \mathrm{ITAL}_\theta} > 0$ and $AGS_\theta > 1$, $AGL_\theta > 1$, θ ε (b, c), imply that the spread and longevity have complementing synergies in domain θ. Further, a greater managerial attention is needed on the overall growth and development of IT architecture synergies since incremental returns to direct effects may be limited and less than the synergistic influences. $\frac{\partial^2 E}{\partial \mathrm{ITAS}_\theta \partial \mathrm{ITAL}_\theta} < 0$ and $AGS_\theta > 1$, $AGL_\theta > 1$, scenario implies that interactive synergies are stronger than direct effects However, because of the substitutive nature of synergies between spread and longevity, the adverse impacts (in case managers do not harness these synergies by simultaneously focusing on spread and longevity) are not likely to be as strong (Siggelkow 2002).

The third ratio, Architecture Growth across Domain (AGD) is the ratio of synergies across the two domains θi and θj, i ≠ j. AGD in this study assesses the relative impact of synergies in the business domain as compared with their impacts in clinical domain i.e. $AGD_{bc} = \left|\frac{\partial^2 E}{\partial \mathrm{ITAS_b} \partial \mathrm{ITAL}_b}\right| \Big/ \left|\frac{\partial^2 E}{\partial \mathrm{ITAS_c} \partial \mathrm{ITAL}_c}\right|$. A value greater than 1 for AGD implies that the synergies between spread and longevity have greater impact in business domain than corresponding synergies in clinical domain.

Eighty percent of the hospitals in our sample have more than one year of average experience, 60% have more than 4 years of average experience, and around 35% of the hospitals have more than 8 years of average experience with a business information system. For the clinical information systems, more than half of the hospitals have less than 7 years of average digitization experience with a clinical technology.

Control Variables: We control for other factors that may impact hospital efficiency. A hospitals' efficiency may be influenced by size, specialty type, and ownership. The number of staffed beds was used to control for the size (BEDStf). We also controlled for learning effects by including the age of the facility as a control (AgeofFac). Further, to control for any potential impacts due to human resources availability, we controlled for the total number of full time equivalent employees at the hospital (HospFTE). We used dummy variables to control for the ownership types - government, non-profit and for profit. In addition, we also control for product mix by including the proportion of revenue from Medicare patients (MCRTCtrl) and Medicaid (MCLTCtrl) patients. Although we had controlled for the proportion of patients through the Medicare or Medicaid route, important differences in performance might arise due to the type of illness for which the patients are being treated at the hospital. Thus we controlled for the case mix at each hospital using Case Mix Index (CMI). The case mix index is a measure of the average severity of illness of patients treated in the hospital. We also controlled for asset intensity by including the ratio of total assets to patients (AsstCtrl). Finally, because the regulatory and competitive environment faced by hospitals differs across states, our sample consists of hospitals only from the state of California. The average size of the hospital measured as the mean number of beds staffed is 196. A majority of hospitals (91%) are general hospitals with the remaining 9% representing children's, psychiatric or other specialty types. Sixty one percent of the hospitals are non-governmental not-for-profit and the rest 39% are either owned by investors, city/county, or district.

Empirical Model

After ensuring that the data did not violate regression assumptions, we estimated the following regression model using net income per patient as the dependent variable (also see Figure 3):

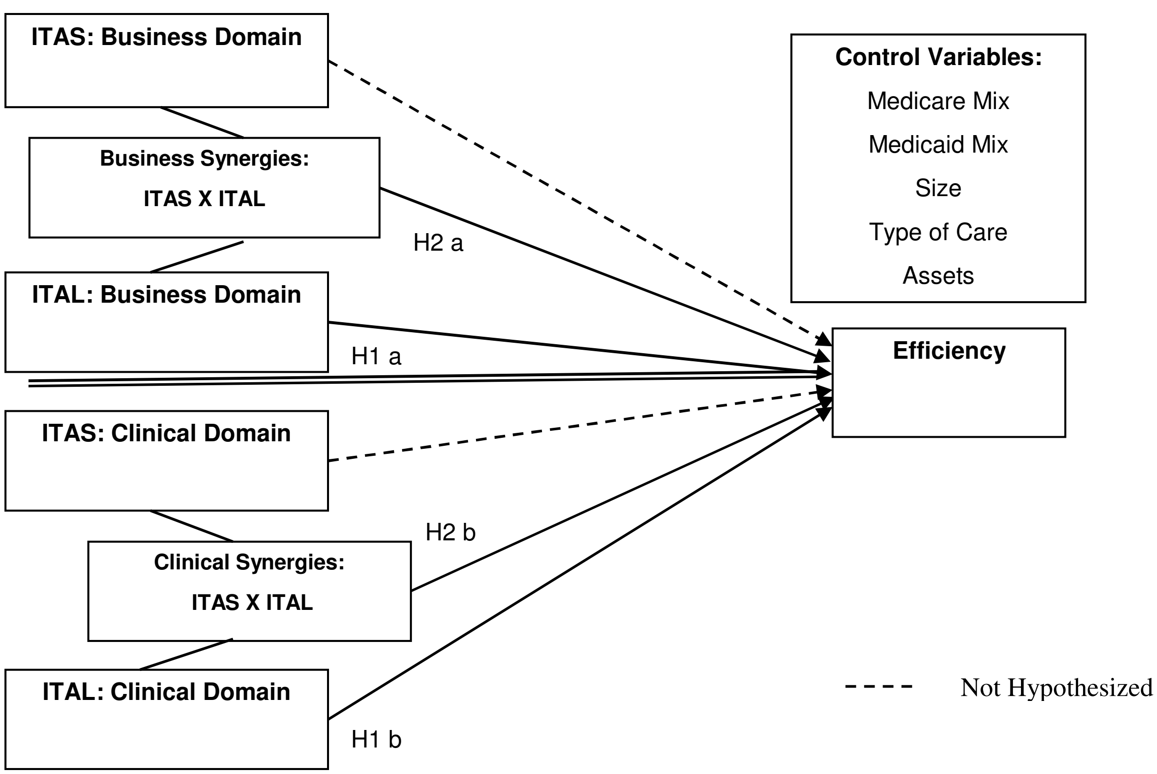

Figure 3. Empirical Model Tested

Results

The results (Table 1, column 3) indicate a positive and significant coefficient on digitization experience within business domain (β=0.83, $p<0.05$). This result is consistent with H1a and indicates that longevity of business domain architecture ($ITAL_b$) yields a positive payoff to the hospital. H1b predicted that greater longevity of IT architecture within clinical domain ($ITAL_c$) will be associated with a significant positive effect on hospital efficiency. However, the results also indicate that longevity with clinical IT is negatively associated with efficiency (β=-056, $p<0.05$). Though the overall impact of ITAL, considering the positive synergies with ITAS, is still positive. Further, H2a, suggests that synergies between ITAS and ITAL within business domain are, in fact, substitutive (Synbnbe) (β=-0756, $p<0.10$; see Table 1). This result suggests that, for business domain, longevity of IT architecture itself is sufficient for improving efficiency. The results for clinical domain however indicate significant positive synergies (β=0.60, $p<0.05$). This indicates that synergies between IT architecture spread (ITAS) and longevity (ITAL) within clinical domain (Syncnce) are associated with a positive effect on efficiency of hospitals, as predicted by H2b. To summarize, the initial assessment of synergies establishes a positive interaction between ITAS and ITAL effects within clinical domain, but finds these to be independent and weakly substitutive in business domain.

Table 1. Regression Results

	Model with Control Effects Only (1)		Full Model (2)	
	Standardized Coefficient	t-statistic	Standardized Coefficient	t-statistic
(Constant)	0.01**	-2.031	0.01	-1.479
CMI	0.286	4.912	0.292***	4.987
BED_STF	-0.091	-0.868	-0.111	-1.043
AGEOFFAC	0.033	0.538	0.031	0.512
HOSPFTE	-0.204	-1.229	-0.238	-1.429
ASSTCTRL	0.072	1.233	0.059	1.011
MCRTCNTR	0.148	1.268	0.196	1.669
MCLTCNTR	0.392***	3.902	0.398***	3.935
Type Care	0.142***	2.599	0.16***	2.872
NPDUMMY	-0.243***	-2.606	-0.221**	-2.36
INVDUMMY	-0.217**	-2.289	-0.174*	-1.793
$ITAS_b$ (ITAS for business domain)			0.123	0.905
$ITAS_c$ (ITAS for clinical domain)			-0.171	-1.093
$ITAL_b$ (ITAL for business domain)			0.833**	2.325
ITALc (ITAL for clinical domain)			-0.559**	-2.212
SynBnBe (Synergies between ITAS and ITAL in Business domain)			-0.756*	-1.966
SynCnCe(Synergies between ITAS and ITAL in Clinical domain)			0.604**	2.079
R Sq	0.240		0.267	
Adj R Sq	0.213		0.223	
F-Statistic	8.754***		6.15***	
R Square Change			0.027*	

Sensitivity and Robustness analysis

We tested whether our data violated the assumptions of regression analysis before conducting the analyses. There were no significant departures from normality and the Breusch-Pagan test for heteroskedasticity and the Linktest for specification errors ruled out any threat to our results due to violation of these regression assumptions. Further, we tested the robustness of the results to violation of distributional assumptions by estimating a non-linear regression.

Test for Endogeniety and Multicollinearity. It is possible that more efficient hospitals invest more in clinical and business IT. That is, efficiency and spread of architecture within business and clinical domain may be simultaneously determined. To rule out this possibility, we tested the robustness of our results using the two-stage least squares (2SLS) technique and compared our OLS results to 2SLS (Greene 2000). The results from the 2SLS were similar to those reported in the full model (Table 1, column 2), which indicates that our results are not likely to be influenced by endogeneity concerns . Further, since we use interactions, multicollinearity might possibly influence the results.

Also, since the interaction is a function of the other independent variables in the regression, collinearity is bound to be induced. To test for any bias due to excess collinearity, we used two tests. Firstly, a ridge regression was performed and the results in this regression run were no different from the original results. Secondly, in case of interactions, ORTHOREG procedure of SAS has been recommended as it offers a more robust test in the presence of interactions and higher order effects. Our results are qualitatively the same with the use of this procedure as well.

Finally, although we had included the total hospital employees to control for the effects due to the human resource availability, we also examined the robustness of our results to the inclusion of a dummy variable which measured if the hospital was a teaching hospital. This was done to control for the operational efficiency that might be realized due to better outcomes facilitated by the research being done at the hospital. This dummy variable was included as an additional control variable and there was no qualitative change in the results after the inclusion of this variable.

Conclusion and Discussion

In this study we examine the performance impacts of two dimensions -spread and longevity - of IT architectures across two work domains in a hospital. These two dimensions – ITAS and ITAL- represent a novel way to classify IT architectures, based on the exploration and exploitation dynamics that have been well examined using similar dimensions in other disciplines such as management and strategy. ITAS measures the range of a hospital's work processes that use information technologies to perform various activities. Hospitals may continuously explore digitization opportunities across newer work processes. However, different hospitals differ in their interest or abilities to comprehend IT capabilities to digitize their work processes, and hence ITAS may differ across hospitals. The second dimension examines the longevity of a hospital's IT architecture and helps assess a hospital's experience with using information technologies within a work domain. As a hospital's IT architecture evolves over time, it develops deep experience with specific technologies to become adept at exploiting and assimilating those technologies. Various adaptations happen as the hospital brings in the needed complementary systems (e.g., business process adaptations, rewards and incentives) (Barua and Mukhopadhyay 2000). ITAL helps assess the performance impacts due to the longevity of IT architecture on efficiency of a hospital.

These two dimensions of a hospital's IT architecture (ITAS and ITAL) represent very different patterns of IT use within hospitals. While hospitals with greater ITAS (i.e. small ITAL) represent an explorative pattern of IT use (signifying a recent induction of a wide range of technologies in the hospital's work processes), greater ITAL alone (i.e. less ITAS) represents a dominance of exploitative pattern (signifying a hospital's greater experience with a limited number of technologies) (also see Figure 1b and 1c). Besides these two extreme patterns, a third IT use pattern is based on the interaction between ITAS and ITAL. This pattern reflects the synergies between ITAS and ITAL within a work domain in a hospital. Hospitals may differ based on the pattern that is most dominant in their IT architectures. In this study we assess how does the efficiency of hospitals vary due to these differences in IT architecture patterns? Impacts of ITAS and ITAL and their synergies help assess the efficiency impacts of these patterns across two different domains of a hospital.

Based on past research, we examine business and clinical as two domains in which the work processes of a hospital are partitioned (Eldenburg and Krishnan, 2007). Clinical IT systems such as cardiology information systems, pharmacy management systems, and laboratory information systems are valuable tools that assist physicians in patient treatment. Physicians view clinical IT systems as critical factors that drive better quality health outcomes

(Robinson and Luft, 1988). Business IT systems such as costing systems, patient billing, nursing staff scheduling, and credit collections are critical tools that are used by hospital managers to ensure smooth administration and drive down costs, while enhancing customer satisfaction with services. IS Researchers have differentiated the performance impacts of information technologies across business and clinical domains in hospitals (Cezar, Menon, Yaylacicegi, 2007). Hence, we examine the impacts of ITAS and ITAL across these two different domains within a hospital.

Table 2. Summary of Results

Relation	Effects	Result
Impact of IT architecture longevity (ITAL) within business domain on Efficiency	H1a	Positive
Impact of IT architecture longevity (ITAL) in clinical domain on Efficiency	H1b	No effect
Impact of IT architecture Spread (ITAS) and longevity (ITAL) synergies in business domain on Efficiency	H2a	Complementary
Impact of IT architecture Spread (ITAS) and longevity (ITAL) synergies in clinical domain on Efficiency	H2b	Weak Substitutive

Our empirical analyses using data from 287 California hospitals examines the effect of ITAS and ITAL and their synergies in clinical and business domains. Results indicate that in the case of business domain, spread of IT architecture does not impact efficiency, but longevity of IT architecture has a significant positive impact on hospital efficiency. In the domain of business systems, identifying specific information technologies and developing deep experience with them is sufficient for improved performance. Since the functionalities of information technologies in business domain (e.g. Enterprise Resource Planning systems, and Billing applications) may overlap, adopting a wide range of these information technologies may be redundant. In contrast, pattern of results is quiet different for the effects of ITAS and ITAL in clinical domain. Longevity of an IT architecture (ITAL) may not yield positive benefits, and may even result in a some negative impact on efficiency. However, the impacts of architecture longevity are positive when synergized with architecture spread. Limited digitization of the clinical domain may hamper the performance of the doctors and nursing staff as they have to coordinate work across a wide range of clinical work processes with different interfaces between manual and digital systems (leading to greater complexity in coordination).

In addition, the interaction between spread and longevity is not found to have positive effects in business domain. Gupta et al. (2006) emphasize that exploration and exploitation should not be de facto considered complementary. In fact, in our analysis, ITAS and ITAL within business domain have a weak substitutive effect. This emphasizes that to some extent a hospital might focus on one instead of the other and still realize the same performance impact. Over time, adaptation with even a few is a substitutive pattern, i.e. IT architectures may focus on an increased spread or longevity to realize similar impacts. However, the interaction between the two has positive effects on efficiency in clinical domain, indicating that ITAS and ITAL have complementary synergies for clinical systems. These results are consistent with those of Cezar et al. (2007), who use data from Washington hospitals and find that expenditures on clinical IT (similar to ITAS in this study) alone do not have either an immediate or a lagged positive impact on hospital performance. Thus, an implication is that hospitals should focus on exploring and adopting a broad range of IT solutions for their clinical domain and develop deep experience with each one of these solutions in order to improve efficiency (also see Table 3 for evaluation and detailed interpretation of AGS, AGL and AGD).

Limitations

The research is not without limitations. While we use the exploration and exploitation paradigm to assess the impacts of ITAS and ITAL in hospitals, we recognize that our measures do not fully capture the complexity and richness of hospital processes related to the two constructs. Other dynamics may influence exploration and exploitation effects within a hospital. Researchers in the field of organizational theory (Holmqvist, 2004, He and Wong, 2004), strategy (Winter and Szulanski, 2001) and managerial economics (Ghemawat and Ricart i Costa,

1993) have highlighted the impact of firm's structure, processes, strategies, and culture on exploration and exploitation. Indeed ITAS and ITAL may reflect on only some aspects of exploration and exploitation which are complex constructs with multiple dimensions, and their definition and connotation has been a subject of wide debate (Gupta et al. 2006). Thus in our secondary data analysis we may only claim that we use proxies that reflect exploration and exploitation. Besides this limitation, the use of secondary data offers objectivity in measurement, though it does so at the expense of the richness that can be captured in more detailed inquiry using survey instrument. Further, secondary data methods have been extensively used in prior research to reflect the exploration and exploitation impacts in other research streams (for example, Rothaermel and Deeds, 2004, Katila and Ahuja, 2002). Hence, though more in-depth inquiry is needed to fully unravel the exploration and exploitation effects in hospital IT architectures, we believe that this study extends the IS literature by conceptualizing the two novel dimensions – ITAS and ITAL. Similar conceptualizations have already been done in the fields of new product development, and hence our research enriches the IS literature by bringing in a new perspective to examine IT impacts. Further, our research will form a basis for future research to explore more in-depth dynamics related to exploration and exploitation and may assess other dimensions of IT architectures. Specifically, certain sub-dimensions of the spread of IT architectures (ITAS) may include – architecture spread variations over certain time periods and hospital types and cultures that may be studied in future research. Finally, it is also plausible that other dimensions of enterprise IT architecture may be examined by future research.

Contributions

The current study sheds interesting insights on digitization of two important domains - clinical and business. Hospital efficiency is an important metric to assess the performance. There is growing interest in the potential of IT to enhance the efficiency of hospital performance and make healthcare services more widely available. Performance assessment is important for calibration of hospitals IT architecture and hence establish reasonable expectation in the formulations of policy regarding the same. However, given the past findings, IT impacts are hard to assess and may involve complex dynamics. Thus, in this research we have taken an enterprise IT architecture view to examine the performance impacts of IT in hospitals. Further, synergies are examined between the dimensions of a hospital's IT architecture. Results have important contributions to the healthcare organizations, and will open up more avenues for future examination of IT architecture impacts in other work domains.

Besides elaborating on the impacts of patterns of enterprise IT architectures on hospital efficiency, our research also makes important contributions to the literature on complementary effects of IT. Recent research has utilized the theoretical lens of complementarities as way of explaining how and why firms could utilize information technologies in shaping superior performance (Sambamurthy et al., 2003, Barua and Mukhopadhyay, 2000). Many empirical studies have examined complementary effects as the integration of IT applications with specific organizational processes, such as customer relationship or supply chain management (Ray et al., 2005; Malhotra et al.2005). Other research has studied complementarities at the level of the enterprise (Aral and Weill, 2007).

However, complementarities may also arise in integration of information technologies within a cumulative set of business processes, which are referred to as activity systems or work domains (Porter, 2001). For example, in their seminal analysis of the shift from mass manufacturing to flexible manufacturing systems, Milgrom and Roberts (1990) argue that complementarities are also generated in firms due to numerous interactions between multiple factors. They state,

"we use the term 'complements' not only in the traditional sense of a relation between pairs of inputs, but also in a broader sense as a relation among groups of activities. The defining characteristic of these groups of complements is that if the levels of any subset of the activities are increased, then the marginal return to increases in any or all of the remaining activities rises (p. 514)".

Table 3. Results of Complementary Estimations

Estimated Statistic	Measure	Value	Result	Inference
AGS_b	$\left\lvert \frac{\partial^2 E}{\partial ITAS_b \partial ITAL_b} \right\rvert \Big/ \left\lvert \frac{\partial E}{\partial ITAS_b} \right\rvert$	Un Defined	Inconclusive	Relative impacts of spread and longevity synergies for the business domain may not be compared in this study.
AGL_b	$\left\lvert \frac{\partial^2 E}{\partial ITAS_b \partial ITAL_b} \right\rvert \Big/ \left\lvert \frac{\partial E}{\partial ITAL_b} \right\rvert$	0	<1	For business domain longevity of a hospital's IT architecture has stronger impact on efficiency than the synergistic impacts[4].
AGS_c	$\left\lvert \frac{\partial^2 E}{\partial ITAS_c \partial ITAL_c} \right\rvert \Big/ \left\lvert \frac{\partial E}{\partial ITAS_c} \right\rvert$	∞	>1	Synergies between spread and longevity and complementing and are stronger than the direct impacts of IT architecture spread.
AGL_c	$\left\lvert \frac{\partial^2 E}{\partial ITAS_c \partial ITAL_c} \right\rvert \Big/ \left\lvert \frac{\partial E}{\partial ITAL_c} \right\rvert$	1.07	>1	Impacts of complementary synergies in clinical domain are stronger than the impacts of longevity of a hospital's IT architecture.
AGD_{bc}	$\left\lvert \frac{\partial^2 E}{\partial ITAS_b \partial ITAL_b} \right\rvert \Big/ \left\lvert \frac{\partial^2 E}{\partial ITAS_c \partial ITAL_c} \right\rvert$	0	<1	Complementing synergies between spread and longevity have a greater impact on efficiency of a hospital than business domain synergies.

Extending prior research on complementarities, our research evaluates interactive synergies in the context of entire domain. We conceptualize ITAS and ITAL as two dimension of a hospital's IT architecture and assess the mutual synergies between the two in a work domain. While synergistic interactions are often proposed to be essential for realizing performance impacts of IT systems, our empirical findings indicate that the significance of these impacts is contingent to the context or domain of work processes. Our results suggest, that in healthcare, synergistic interactions between spread and longevity of IT enterprise architectures are more likely to materialize in the domain of complex activities (typical in clinical domain). On the other hand, in the case of relatively simpler domain, such as that of business related activities in a hospital, ITAL may be sufficient to produce higher efficiency. Hospital industry offers a set of standardized work processes and related information technologies that could be easily compared across hospital. Future research could examine whether these results hold in other industries as well.

Finally, our empirical estimation of complementarities has added to the literature on complementarities estimation by developing three new ratios. The concepts of Architecture Growth to Spread (AGS) and Architecture Growth to Longevity (AGL) have helped determine the impact of synergies relative to the direct impacts. The relative impact of synergies across business and clinical domains are assessed using the ratios AGS, AGL and AGD (also see Table 3 for evaluation and interpretation of AGS, AGL and AGD). Our systematic assessment of these effects will help establish a framework that will guide a more through empirical assessment of IT architecture interactive synergies in future research.

P.S.: The list of technologies is available upon request from the authors

[4] Even considering the weakly significant substitutive impacts AGL_b is less than 1 implying that while experience has a strong positive impact on performance, adopting a wide range of business technologies across digitized processes can compensate a lack of experience.

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