A Model of Process-Based Automation:

Cost and Quality Implications in the Medication Management Process

by

Trent Joseph Spaulding

A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctorate of Philosophy

Approved April 2011 by the
Graduate Supervisory Committee:

Raghu T. Santanam, Chair
Ajay Vinze
Michael F. Furukawa

ARIZONA STATE UNIVERSITY

May 2011

ABSTRACT

The objective of this research is to understand how a set of systems, as defined by the business process, creates value. The three studies contained in this work develop the model of process-based automation. The model states that complementarities among systems are specified by handoffs in the business process. The model also provides theory to explain why entry systems, boundary spanning systems, and back-end control systems provide different impacts on process quality and cost. The first study includes 135 U. S. acute care hospitals. The study finds that hospitals which followed an organizational pattern of process automation have better financial outcomes. The second study looks in more depth at where synergies might be found. It includes 341 California acute care hospitals over 11 years. It finds that increased costs and increase adverse drug events are associated with increased automation discontinuity. Further, the study shows that automation in the front end of the process has a more desirable outcome on cost than automation in the back end of the process. The third study examines the assumption that the systems are actually used. It is a cross-sectional analysis of over 2000 U. S. hospitals. This study finds that system usage is a critical factor in realizing benefits from automating the business process. The model of process-based automation has implications for information technology decision makers, long-term automation planning, and for information systems research. The analyses have additional implications for the healthcare industry.

DEDICATION

I dedicate this work to my wife, Christy, who sacrificed more than anyone else to allow me to complete the requirements for this degree. I would not have started or finished without her encouragement. Beyond giving so much she actually read and commented on this whole document multiple times. I also dedicate it to our children: Aubry, Miriam, Mark and Michelle.

ACKNOWLEDGEMENTS

I am very grateful to my dissertation committee and the department of Information Systems for their support and sponsorship of this work. Each member of the committee has been vital to making this work what it is. I particularly acknowledge my advisor. Raghu has been a patient and kind friend in making time when I need to talk. Raghu, Ajay and Mike have been very supportive. They have changed the way I think and work.

This work has also benefited from presentations at department seminars at Arizona State University, at Appalachian State University with the Heath Care Management group, at the Hawaii International Conference on Systems Sciences, the International Conference on Information Systems, and the Americas Conference on Information Systems. Further, I acknowledge the department of Information Systems and thank them for making the funds available for the IT usage data in the third study.

TABLE OF CONTENTS

CHAPTER Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Chapter 1. Introduction

According the Centers for Medicare and Medicaid Services, spending on healthcare in the United States has grown to over 17% of GDP.[1] Despite all this spending, the U.S. still ranks near last in terms of quality among developed nations (Davis et al. 2010). The belief that information technology can alleviate some of this cost while improving quality is evidenced in the Health Information Technology for Economic and Clinical Health Act of 2009 (HITECH). This dissertation examines the impacts of health information technology on cost and quality.

Recent IS literature has called for research to guide "manage[ment] of the HIT implementation process" and states that "[t]his is possibly one of the most pressing health policy issues facing the nation" (Agarwal et al. 2010, p 801). Information systems are often implemented and studied with little consideration of the end-to-end business process. The information systems literature recognizes the relationship between systems and processes in healthcare and in general (Barua and Whinston 1998, Devaraj and Kohli 2000). A business process within a large organization generally is automated by several different information systems. This dissertation claims that in order to understand the value created within the process by these systems, researchers must consider the whole set of systems at once.

---

[1] The National Health Expenditure Fact Sheet: https://www.cms.gov/NationalHealthExpendData/25_NHE_Fact_Sheet.asp

The objective of this research is to study how information systems create value within a business process by (1) the role the system plays in the process and (2) by interacting with other systems. Automation of individual tasks often creates efficiencies and quality improvements. This fact has been well investigated in many contexts (e.g. Hitt and Brynjolfsson 1996, Devaraj and Kohli 2000, Davamanirajan et al. 2006). However, very little work has been done to understand how a set of systems works together. The literature review and the three studies contained within this dissertation are all within the scope of the following research question: How do sets of systems, as defined by the end-to-end business process, create cost and quality improvements? A whole or complete set of systems includes all the information systems needed to automate a business process from initiation to completion.

Examining the role of systems and interaction between systems with in a process requires multiple different perspectives. The first is that different patterns of automation should lead to different outcomes. To use an example from the healthcare industry, hospitals which focus automating systems internal to organizational units may have different cost and quality outcomes than hospitals which focus on organizational boundary-spanning or process front-end systems. The second perspective sees integration of systems as a critical component of value creation. More value will be created by the electronic medication order entry system if there is a pharmacy information system in place to receive that order. The third perspective is that usage of process IT is critical to the efficacy of process systems in impacting process cost and quality.

Together, these three perspectives can provide an informative view on how information systems within a process create value. The studies which focus on the first two perspectives test the hypothesis that the systems are in fact interacting to create value and that the systems play different cost and quality roles in the process. The third perspective examines the assumption of the first two that the systems are in fact being used to create value. The theory gathered and evidence accumulated from all three perspectives provide the puzzle pieces of the model of process-based automation.

Viewing value creation by information systems from this perspective requires an unusual compilation of data. Most studies in this industry are either small panel sets or large cross sectional data gathered from one or two sources (see Chapter 2, Section 4). Addressing these three perspectives requires three different data sets compiled from over five different sources. The data sets include financial, quality, hospital demographics, and healthcare IT measures for U.S. hospitals over 11 years.

To address the first perspective, the first study recognizes that most business processes are automated in a piece-meal manner. The observation that different organizations will automate the tasks of a process in a different order leads to the following question: Does the order of automation of the tasks in the process have an effect on cost outcomes? Order of automation does not refer to the order of the tasks of the process but to the order of implementation of the systems. The study presents an organizational model of automation and an operational model of automation. Testing the effect of order of automation on process outcomes requires data on the timing of implementation of each system of the process for each hospital studied. This measure is calculated from 10 years of the HIMSS Analytics survey. The data are also merged with data from the American Hospital Association (AHA) as well as data from the Center for Medicaid and Medicare Services (CMS). The results show that better financial outcomes are associated with specific patterns of automation. From a healthcare perspective, this study shows the importance of respecting organizational boundaries within the hospital. Hospitals which followed an organizational pattern of adoption were associated with better financial outcomes.

The second study recognizes the need for continuity of automation within the business process. Jason Hess, research director for the medical technology evaluation firm KLAS made a similar observation, “If you go to the expense of getting your physicians engaged and doing [Computerized Physician Order Entry] - and that's a huge undertaking - when that order gets to the pharmacy, you've got somebody re-keying it from one screen to another screen. Think about how inefficient and unsafe that is…If you're going to do CPOE, get the pharmacy integrated” (Lawrence 2009). The observation that all processes are not contiguously automated leads to the following question: Does automation continuity or discontinuity have an impact on cost and quality? Discontinuity of automation means either a switch from automated to manual or from manual to automated tasks. Continuing to build on the theory from the first study, the model of process-based automation suggests that discontinuities in the process lead to higher costs and lower quality. The data represent 259 acute care California hospitals over 11 years. Main data sources are HIMSS Analytics and the California Office of Statewide Health Planning and Development (OSHPD). The analysis supports the prediction that discontinuities increase costs and decrease quality. The study finds that hospitals may be able to increase quality and decrease some costs by focusing automation of integrated systems.

An assumption of the first two studies is that the medication management systems are being used. The final study recognizes that system use is an important factor in the ability to realize value from implementation of a set of systems. Does system use play an intermediate role between systems implementation and cost and quality outcomes? System use in this case means the percent of transactions or orders that enter the automated system. In many organizations there are work-arounds implemented for some percent of transactions in order to avoid the controls or user interface of the system. Theory suggests that not only can usage affect cost and quality after implementation is complete, but that there are factors related to the implementation of the set of systems that can impact usage. This study includes over 2000 U.S. acute care hospitals. The cross-sectional data include 2007 data from HIMSS Analytics, AHA, CMS, and the Hospital Quality Alliance (HQA).The findings of this final study support both the hypothesis that information technology (IT) factors affect use and that system use is related to overall costs.

Many other issues could be addressed under the umbrella of sets of systems defined by the business process. For example, the first study observes the evolution of a set of systems over time. This perspective presents other opportunities. Vendor behavior and vendor lock-in can provide interesting insights from both the vendor and the client perspective. Different approaches to implementation may have different impacts on cost and quality such as piece-meal implementation versus big bang implementation. Often a system may be involved in many different processes. Application sets and process characteristics for secondary processes may have implications for the impact of systems within the primary process. Although these issues are interesting, the issues addressed in the three empirical studies of this desertion are foundational to the others. The three perspectives of the empirical pieces view systems interaction, integration, and roles of the systems in the process more generally. The issues of vendor behavior and lock-strategies, client strategies, big-bang adoption, and many others will build on the theory and evidence revealed in the first three perspectives.

Answering the questions posed for the described studies requires a broad set of methods. All three studies rely on secondary data. The first study requires sequence analysis using Levenshtein differences to calculate difference between hypothesized patterns of automation and actual patterns (Levenshtein 1966). These distances are then handled with WLS regressions. The second study provides panel data which is analyzed using a fixed effects model. The final study involves a more complex model with use as an intermediate outcome. It could not be implemented using a simple two-step model because evidence of selection bias exists in the data. Therefore a Heckman selection model is implemented using an ordered probit as the selection equation (Heckman 1979, Chiburis and Lokshin 2007).

This dissertation should be evaluated in the context of healthcare IT, complementary innovations, value of IT, and business process literature. The review of healthcare IT and particularly the value of healthcare IT provides the context in which the studies should be evaluated and interpreted. Literature on complementary innovations provides initial theoretical reasoning for why complementarities exist. It postulates that business processes may be major determinant of which systems integrate. Business process and operations literatures provide foundational theory about which tasks are most critical to automate.

From the perspective of IT management literature, this research makes progress on three fronts. The first is the development of a model for process-based automation. This model is the first to propose the business process as a powerful tool to define complementarities between systems. Much of the empirical work on complementary systems is exploratory in nature (e.g. Golob and Regan 2002, Smith and Weil 2005). This model suggests that the business process is the basis for defining a set of systems which interact and create synergies. Further, the role of the system in the process affects the relationship between automation of the task and cost and quality outcomes. Examples of these roles include entry points, control points, and boundary spanning systems. Finally, because the process is the context in which value is created, systems usage is a critical determinant of the efficacy of process systems.

The second type of contribution includes measures of process IT. Studying the order of automation and measurement of that order using the Levenshtein distance is novel. Possibly the closest study to this work is Angst et al (2011) which observes that the order of automation and should be recognized. However, their work is focused on hospital-level IT instead of process level. This dissertation is also the first to measure the amount of automation discontinuity within a process. The final empirical analysis includes the effects of both automation and usage.

The third type of contribution of this work is strong management implications which have been tested using large data sets. The model of process-based automation should influence decision makers, particularly in long-term planning and automation of whole processes. Automation decisions cannot be made without considering the whole process. The model suggests that there are points in the process for which automation will provide better returns on investment in quality and cost.

The remainder of this work is organized as follows. The following chapter reviews relevant literature in complementary innovations, business processes and operations, and healthcare IT which form the basis of this dissertation. Chapters 3, 4, and 5 discuss each of the three perspectives of process-based automation. They progressively develop the research model. Each study discusses in more detail the data sources and tests different parts of the research model. The final section brings together the findings of the three studies and the model which they develop. It also discusses interpretations and implications of the three empirical pieces as well as the future program of research.

Chapter 2. Literature Review

2.1. Introduction

A growing body of literature shows conflicting findings on the value of IT in healthcare. Some studies claim that IT is detrimental to quality measures (Wu and Straus 2006). Others show slight improvements (e.g. Menachemi et al. 2008). This dissertation proposes that much of these weak and negative findings can be clarified using a processed-based approach to automation. Bring clarity to the value of healthcare IT discussion by using the process requires a theoretical foundation in business processes, complementary systems and innovations, and the value of IT. Business process and operations literature provides a foundation for organizational and operational factors related to business processes. There is currently a large body of research related to the value of IT. This literature review focuses mainly on studies related to healthcare IT as these studies are most relevant to the three empirical pieces. The scope of the literature review is to lay the foundation for the empirical pieces. Specifics of theory development and literature related to methodologies are discussed in further detail in the studies themselves.

The first section of this literature review will cover complementary innovations. The traditional definition of complementary innovations is that the two innovations together can provide better results than could the sum of the two innovations individually (Barua et al. 1996). The second section discusses business processes and operations. Business process can define the points of integration between complementary systems as well as where to measure improvements in cost and quality. After exploring the literature in these areas, healthcare research relevant to these studies is reviewed.

2.2. Value of Information Technology – The Case of Multiple Systems

The value of information technology in modern environments requires the evaluation of multiple systems. Each system may add some value on its own. It is argued that it is the combination of systems, devices, and functionality and the complementarities created by them that produce the most benefit. Barua et al. (1996) state that complementarities exist when increasing one factor increases the benefits of the other factor. These complementarities arise due to contingent benefits, learning effects or absorptive capacity, and technical capabilities. Bucklin and Sengupta (1993) define contingent adoptions as the case when adoption of one technology requires adoption of another. An example of this case is word processing software and personal computers. To adopt word processing software, one must also use a computer. While contingent adoption is an important facet of information systems adoption, many important business process contexts involve non-contingent adoptions.

Complementarities may exist because of learning effects or absorptive capacity (Wozniak 1984, Stoneman and Kwon 1994), technical compatibilities (Colombo and Mosconi 1995), or other business factors (Barua et al. 1996). When complementarities are due to learning effects and absorptive capacity, individuals and organizations can better realize value from a second system when they have successfully implemented the first. Complementarities due to technical compatibilities result in less effort in integration, conversion, or transfer of information between systems such as between computer-aided drafting and computer-aided manufacturing techniques (Colombo and Mosconi 1995). Other business factors relate to business processes and business initiatives such as business process management (e.g. Barua et al. 1996).

While the theoretical foundations for value due to interactions among IT are strong, empirical characterization of these interactions can often be challenging. As a result, a number of different approaches have been utilized to examine complementary systems adoptions. Two recent empirical works suggest that business process contexts can act as contributors to contingent adoption. The first, Smith and Weil (2005) proposed a "ratcheting up" theory from their observations of the diffusion of retail technologies into both manufacturing and retailing organizations. Their results supported the assertion that downstream adoptions can influence adoption of technologies by upstream partners. Thus, the more advanced the retailer, the more likely manufacturers will adopt. A second approach to the evaluation of multiple systems within a process has been a staging approach. Furukawa et al. (2010c) studied the effect of Electronic Medical Records (EMR) stages on several cost and quality related outcomes including nurse cost per hour. An EMR is an integrated set of information systems within a hospital. Although they did not find large cost savings, they did see a decrease in hourly rates over time.

When complementary innovations do exist, studying them separately can lead to misleading results. Stoneman and Kwon (1994) studied the adoption of numerically controlled machines and carbide coated tools. These technologies are defined as complementary or synergistic because they create more benefits together than the sum of the benefits from the individual systems would be. Stoneman and Kwon built on an earlier study (Karshenas and Stoneman 1993) which found weak results while observing a single technology. Stoneman and Kwon also found that price and epidemic effects are more significant when considering multiple technologies. Interestingly, the effect of the cost of technology B on the adoption of technology B changes when an organization has already adopted complementary technology A. Colombo and Mosconi (1995) likewise found that models which do not include related technologies are likely mis-specified. Colobo and Mosconi's study focused on computer aided drafting and computer aided manufacturing which are both technologies from the flexible automation paradigm. Significant interactions between the adoptions of these two technologies were revealed. Use of prior technologies also has a significant effect on the adoption of the newer technologies.

Golob and Regan (2002) investigated the adoption of seven trucking technologies in a rigorous exploratory study. Golob and Regan used a multivariate discrete choice model which allowed them to observe not only the relationship between firm characteristics and adoption of each innovation, but also the effect of adoption of one innovation on the other innovations. They found that most of the seven technologies they consider in the study are positively correlated. Though their findings appear to be robust, they do not propose any theory to explain the nature of the complementarities of these systems.

Smith and Weil (2005) proposed a “ratcheting up” theory from their observations of the diffusion of retail technologies into both manufacturing and retailing organizations. They found that the more advanced the retailer, the more likely manufacturers will adopt. The process of ratcheting up is driven by the fact that retailers and manufacturers benefit from synergies of using compatible systems. Though simple, this hypothesis is reasonable. However, it needs to be generalized to explain why systems are built to be compatible with each other. Such a theory could help researchers recognize the existence of complementary systems and appropriately adjust adoption models to account for complementarities. Decision makers could also make more informed decisions by recognizing potentially complementary systems, even when those systems have not yet been introduced into an industry.

The most important consideration that this handful of studies of complementary systems reveals is clear. When information systems are part of a larger process or collection of systems, adoption decisions must be evaluated with the knowledge of the related systems and processes.

Table 1 Literature on the Adoption of Complementary Innovations

	Industry	Innovations	Findings
Wozniak (1984)	Agriculture	Hybrid Corn, fertilizers, growth-hormones	Complementary innovations have positive influence on each other, new innovations are more likely to be adopted when compatible with previous adoptions
Stoneman and Kwon (1994)	Manufacturing	Numerically controlled machines, carbide coated tools	Price effects and the epidemic model are more significant when accounting for more than one technology, adoption of A changes the effect of the price of B on the adoption of B
Bucklin and Sengupta	Retailing	Scanners, UPC symbols	Co-diffusion effects are stronger than simple
Colombo and Mosconi (1995)	Manufacturing	Computer aided drafting (CAD), computer aided manufacturing (CAM)	Adoptions of CAD and CAM had a significant effect on each other, adoption of previous technologies was correlated with adoption of CAD and CAM
Golob and Regan (2002)	Transportation	7 technologies used by truckers (EXPOUND)	The adoption of most of the technologies studied had a positive influence on each other
Smith and Weil (2005)	Retailing	EDI, scanning equipment, bar-coding	IT adoption in one part of the supply chain encouraged adoption in other parts of the supply chain.

2.3. Business processes

Extant literature has long considered the strong inter-relationships between business processes and information systems (e.g. Davenport and Short 1990, Hammer and Champy 1993). Information systems automate business processes, inform decision making, and contribute to quality management. According to Davenport (1990), IT capabilities change business process design and create possibilities for process innovation. The synergistic interplay between information systems and process innovations is recognized as a significant contributor to productivity improvements from reengineering initiatives (Barua et al. 1996). In fact, information systems researchers have cautioned managers to not ignore the process perspective when adopting information systems. For example, when information systems simply automate and do not consider changes to the underlying process, they do not reach optimal improvements (Stoddard and Jarvenpaa 1995). Despite the strong interactions, implementing process changes associated with information systems is a difficult undertaking. Organizations face difficult decisions in automating processes due to technology, workflows and organizational considerations.

A close relationship exists between information systems and business processes. In business environments, information systems automate business processes, inform decision making, and contribute to quality management. A business process is initiated by a stakeholder and isn't complete until the final outcome is satisfied from the perspective of the stakeholder (Burlton 2001, p 72). According to Raghu and Vinze (2007) "business processes are … collection[s] of interdependent activities or tasks organized to achieve specific business goals" (p 1064).

2.3.1. Automation and process variance control

Three process related factors are foundational to this work and will be addressed in the following order. First, variance reduction in process output is often one goal of automation. Second, automation influences process costs in terms of required labor and skill sets. Third, the process and actors in the process are situated in an organizational context. The model of process based-automation developed in the following chapters is built on these process factors.

Variance reduction is a strong motivator for business process automation. The theory of constraints suggests that mechanisms controlling variance should focus on factors which cause the most variance (Goldratt and Cox 1984). Out-of-bounds variation at each stage of a process will cause subsequent stages to wait for acceptable output. This impact of waiting accumulates as each station introduces additional variance. Variance in business processes also tends to have a bullwhip effect (Lee et al. 1997), especially when those processes include imperfect information and long lead times. Therefore, when information systems implementation strategy considers the end-to-end business process workflow, it will have a greater effect in improving the overall business process performance.

Automation at each step of the process will be a key factor in reducing variance due to human error and human judgment in data input. While practitioners generally accept the importance of an end-to-end process view, implementation is often fraught with challenges. Most importantly, different units within the process may experience different outcomes as a result of the changes to tasks and roles they perform in the automated environment. When some units encounter higher costs or a reduced prominence due to the change, they may reject the process innovation outright or create workarounds to sabotage the process innovation.

Variation in process outcomes can also be due to multiple points of data entry and data reconciliation. In calling for a recognition of the business process context, Raghu and Vinze (2007) stress the need to minimize coordination costs related to information processing. The information processing perspective suggests that a process will benefit from capturing data at one source and conveying that information through the process in an automated fashion. If information is not captured at the point of origin, duplication of tasks and information collection or input can result. At some point in the process, information collected at various points will need to be reconciled. Information reconciliation is labor intensive and has the potential to increase process cycle times. As a result, Hammer and Champy (1993) push the principle of minimization of reconciliation through process design. Buzacott (1996) provides a very simple theoretical explanation for the optimality of this design principle. When two parallel paths of information flow have to be reconciled, the probability of reconciliation error is greater than the errors in the individual paths. Therefore, automation and, more specifically, continuous automation of business processes should lead to improved process performance.

2.3.2. Automation and process labor costs

Automation of the business process also leads to changes in the skill set required to complete a task (Schumacher 2002). Skill bias theory says that when more interaction with technology is required, then higher skilled workers (evidenced by higher pay rates) will be required. Schumacher found that "technological change has resulted in an increase in demand for higher skilled workers in the [healthcare] industry" (p 412). The finding also noted decreased demands for lower-skilled workers. The skill bias argument posits that technology automates repetitive tasks, thus reducing the need for cheaper labor. On the other hand, the more technology is involved in the process the more the workforce must be technologically sophisticated, thus requiring more expensive labor. However, when some steps in the process are not automated, the discontinuities will require additional reconciliation and data transfer tasks. Low skilled workers can often fulfill such tasks. Therefore, process automation is effective when it can reduce unskilled labor requirements and increase the involvement of skilled labor.

2.3.3. Automation and the organizational context of the process

Most business processes involve participants from multiple levels and functional divisions of a business (Raghu and Vinze 2007). The interdependence of activities of the business process requires that decision makers consider all participants, inputs and activities when making changes to the business process. Because process tasks and information systems are potentially located in different organizational units, power and politics becomes an important consideration in the value created by systems working across intra-organizational boundaries

(Markus 1983). Initiatives to automate processes across organizational hierarchies often face organizational challenges implementing the optimal solution such as the distribution of power, management support from multiple sub-units, and management willingness to impact people (Markus and Robey 1988, Kettinger et al. 1997). "Technochange" or changing the organization through IT involves significant risks and therefore, significant efforts and expenses must be made to ensure successful automation and adoption (Markus 2004). Organizational effects come from both the relationships between organizational units and the characteristics of the larger organization.

Grover et al. (1995) studied business process reengineering. Through literature review and interviews they found over 60 issues that hinder the successful process reengineering projects. They classified these issues into six areas: management support, technological competence, process delineation, project planning, change management and project management. Of particular interest to this research, process delineation encompasses the inclusion and buy-in of process owners and the ability to define and agree on process improvement goals. In siloed organizations, organizational boundaries can mean that improvement goals are not common among all the players in a business process.

Individuals involved in the business process are also employees of a department and are likely to be more familiar with their task than they are with the whole process. Therefore, individuals are more likely to make decision congruent with organizational realities. In such contexts, information systems may be adopted to support limited aspects of a business process. This conclusion is congruent with Daft's (1978) and Swanson's (1994) multiple core models. Nevertheless, such an adoption strategy is not necessarily optimized for best business performance. For example, if two or more activities are automated in a process and but the process information is not completely connected, the process will require that inputs at individual steps in the workflow be entered into multiple computer systems. Multiple inputs create inefficiencies and opportunity for error (Buzacott 1996).

In summary, the literature reveals three factors which influence the value of multiple information systems working together. First, automation has the potential to reduce variance by streamlining information flow and workflow in business processes. Second, automation can change the skill set required to complete a process. Finally, despite the operational benefits of continuous automation, the organizational context of the business process may affect the efficacy of system interactions.

Improvements in the process should be greater where complementarities exist. The organizational, input, and variance correction factors assert that these complementarities should be found in large part where information must move between tasks and entities in the business process. Given the same number of systems, less labor will be needed to gather and use information from different organizational units if the process is continuously automated. Given the same number of systems, less labor will be required to input, interpret, or transfer information when systems are continuously automated. Finally, given the same number of systems, less labor will be required to correct variance when systems are continuously automated. When systems are not continuous, they may increase variance by introducing opportunity for data input error and reconciliation of data and data formats. Systems which are continuous, according to information flow in the business process, should lead to labor cost savings. Therefore, when studying the value realized from implementing IT, the focus should not only be on the process level, but on the process as a whole.

From business process reengineering to the simple flow of information between participants, information systems is integral to business processes. It is the business process which defines how the systems are to be built and how the systems are to interact. Research on the adoption of information systems within large organizations must therefore use business processes to understand the complementary effects within the process.

2.4. Healthcare IT

Healthcare IT is unique in that automation of hospital processes has been much slower than the mainstream business world. Only 1.5% of U.S. hospitals have an extensive electronic medical records system (Jha et al. 2009). Adoption of healthcare information technology is often related to organizational and hospital variables. Menachemi et al. (2007) found that hospitals which received more patients under managed care had higher adoption of clinical and administrative IT. Other studies have found that governmental hospitals had adopted less CPOE (Cutler et al. 2005, Furukawa et al. 2008). Gans et al. (2005) found that electronic health records were adopted first by larger organizations. This means that implementation of hospital IT is dependent on the size of a hospital and the demographics of that hospital. These factors also affect outcomes such as patient safety and hospital profitability. Poon et al (2004) conclude that financial incentives and public pressure are the largest motivators for physicians to use CPOE. Poon et al. (2004) also noted that quality of IT in a hospital has an effect on the ability of an organization to successfully implement CPOE. This means that the successful implementation of new hospital IT will be somewhat dependent on the quality and amount of IT the hospital has previously managed.

One of the most recognized works in healthcare IT performance shows the importance of process and IT alignment in realizing process improvements. Devaraj and Kohli (2000) conducted a panel study of eight hospitals over three years. They found that IT had an effect on revenue per admission and per patient day. They also found that business process reengineering decreased mortality and increased patient satisfaction. Together BPR and IT had a greater effect on revenue per adoption and per patient day. The positive findings of this study are interesting. However, the sample size was small and they focused only on decision support systems. Another issue is the use of revenue per admission and per patient day. Hospitals may simply charge more per patient if they are supporting a larger IT budget thus creating endogeneity issues.

Conclusions of past research on the performance impacts of information systems within hospitals have been highly mixed. Cutler et al (2005) concluded that hospitals which implement CPOE are not more profitable than those who don't. From a study of Boston and Denver area hospitals, Poon et al. (2006) conclude that hospitals' implementation of IT is biased toward functionality with financial benefits. This suggests regulation and policy may be needed to more fully implement functionality focused on quality and safety which does not have financial benefits.

Some studies have shown that IT has a negative effect on quality. Culler et al. (2007) studied the association of hospital information systems and patient safety indicators provided by AHRQ. They found that only one indicator of quality was affected in a positive way. Three others were negatively affected. Some hospital IT has been shown to have a detrimental effect on diagnoses and efficiency. Wu and Straus (2006) came to a similar conclusion in their review of research on handheld devices in electronic medical records. The use of the handheld devices increased documentation, but it also increase time to document and was correlated with wrong or redundant diagnoses.

Menachemi et al. (2008) studied healthcare IT from a multi-core perspective similar to the approach taken by Daft (1978) and Swanson (1994). They found that clinical, administrative, and strategic IT have seven desirable effects on quality in 98 Florida hospitals. The quality measures in their study focused on post-procedural mortality rates, in-hospital mortality rates, and utilization of procedures. The findings of Menachemi et al. conflict with many studies that have found only weak relationships or undesirable relationships between mortality and IT (e.g. Culler et al. 2007). Though these findings are interesting, the theoretical and physical gap between some of the independent variables (such as strategic IT) and the mortality rates is large.

In sum, the mixed findings of prior research are likely related to the level of investigation. For example, hospital profitability is based on much more than the use of CPOE. Quality indicators that are often used, such as the patient safety index, are often more affected by quality initiatives and organizational culture more than the implementation and use of individual systems. However, the availability of data has likely caused this gap. Future research in the area needs to focus on a business process and the performance metrics of that process. Future research must also take into account the fact that the implementation of IT in a hospital is a complex process which creates endogeneity issues when studying performance.

Table 2 Healthcare IT Studies Related to Medication Management Systems

	Independent Variables	Dependent Variables	Sample	Findings
Cutler et al. (2005)	CPOE level of implementation	Net income per admission	751 Hospitals	No significant effect of CPOE on Net Income, differences in CPOE adoption by hospital characteristics
Poon et al. (2006)	N/A	CPOE Adoption	Qualitative interviews from 52 provider organizations (hospitals, practices, etc.) in Denver and Boston	Financial benefits are driving functionality adoption (not quality)
Culler et al. (2007)	Availability of 97 IT systems	AHRQ Patient Safety Indicators (PSI)	66 community hospitals in Georgia	One PSI indicator was positively affected, three others were negatively affected
Wu and Straus (2006)	Handheld Devices	Time to documentation and wrong or redundant diagnoses	Meta study combining two previous studies on handheld devices in healthcare	Handheld devices ↑ time to documentation and ↑ wrong and redundant diagnoses
Menachemi et al. (2008)	Adoption of administrative, clinical and strategic IT	AHRQ Inpatient Quality Indicators (IQI)	98 Florida hospitals	Adoption of clinical administrative and strategic IT combined had 7 positive effects
Devaraj and Kohli (2000)	Decision Support Systems, BPR initiatives	Quality, mortality, patient revenue, patient satisfaction	8 hospitals over 3 years, monthly	IT ↑ patient revenue and ↑ quality BRP ↓ mortality and ↑ patent revenue BPR and IT together ↑ patient revenue
Menachemi et al. (2007)	Payer mix	Adoption of administrative, clinical and strategic IT	98 Florida hospitals	% of payments from managed care ere associated with increases in clinical and administrative IT
Yu et al. (2009)	CPOE use	Quality measures from the Center for Medicare/Medicaid Services and the Hospital Quality Alliance	3364 Hospitals	CPOE use for 100% of orders is associated with better performance in several quality measures

2.5. Conclusions

From a healthcare perspective, the following three empirical works will help to explain some of the differences between the studies that have found little or no value and those that have found a lot of value in healthcare IT. The value of healthcare IT suggests that some of those findings will be on the hospital level, but that most findings will be at the process level. The healthcare literature also suggests that future work should investigate issues of endogeneity between performance variables and IT variables. Finally, evaluations of the automation decision must also include variables of prior adoptions or the status of current IT in the organization. Research which effectively addresses these issues has potential to authoritatively address the continuing debate on the performance effects of IT in hospitals.

From the perspective of the management information systems literature, research focusing on the entire set of applications involved in the business process is likely to make contributions on several fronts. First, relatively little work has been done to address the issue of interdependence among multiple systems in a process. Second, general principles describing the interdependence of information systems may evolve from the study of the automation of business processes. Finally, the adaptation of multi-core models to include the interactions between organizational units may lead to new frameworks or heuristics to assist decision makers in evaluating the benefits of each new system in the process.

The next chapter presents a hospital level picture of how the automation decision should be made in the context of previous automation decisions within the business process set of applications. After addressing these interdependencies on a hospital level, the second and third studies take a process-based approach to the dependent variables. The second study addresses application interdependence by measuring the amount of discontinuity of those systems. The final study will then focus on the effects of IT on use and the effect of use on cost and quality.

Chapter 3. Event Sequence Modeling of IT Adoption in Healthcare

3.1. Introduction

Health care costs and efficiency concerns continue to dominate healthcare policy discussions despite numerous regulations and reforms. In response to a number of recent initiatives and regulations, hospitals have been investing in Health Information Technologies (HIT) to address cost and efficiency concerns. With a variety of efforts underway, the impact of these investments remains unclear. More recently, a number of studies have begun to show that HIT can actually increase costs and reduce efficiencies in hospitals (Furukawa et al. 2010b, Furukawa et al. 2010a, Furukawa et al. 2010c). Interestingly, there is wide variation in adoption across technologies, hospital characteristics, and geographic locations (Furukawa et al. 2008). These variations in adoptions suggest that hospitals may be using distinct strategies in HIT investments to address costs and efficiencies. This connection between adoption strategies and process outcomes is explored using a theoretical rationale from the business process management literature to understand HIT adoption patterns in hospitals and the resulting impact on performance. The analysis adapts an event sequencing approach to model and identify distinct adoption strategies among hospitals.

Business processes create the organizational and operational contexts for adoption of IT innovations (Raghu and Vinze 2007). As a result, both academic and practitioner literatures emphasize the need for aligning IT strategy with business strategy (Alter 2007). When IT and business strategies are aligned, complementarities and synergies from adopting IT systems can be enhanced.

While there are strong arguments for alignment, achieving alignment continues to be a challenge in organizations. The primary reason for this is that business processes typically cut across divisional and functional boundaries where power and politics may create challenges and conflict among stakeholders (Markus 1983). The contingent nature of these organizational challenges can motivate organizations to follow different paths of IT systems adoption.

Though adoption of interrelated IT applications has been studied in the literature, the use of a business process orientation to understand adoption of technology in this context is not sufficiently documented. To the best of the author's knowledge, no studies exist in IS literature that have specifically considered IT adoption paths and the impact of those paths on financial performance. Previous research in other industries has empirically documented that there are strong correlations in technology adoption decisions in organizations. In the transportation industry, Golob and Regan (2002) studied adoption of seven different IT systems and discovered tendencies for bundled IT adoptions in firms. However, their work did not investigate paths of adoption nor did it investigate related performance impacts. Smith and Weil (2005) investigated the possibility of adopting manufacturing technologies in sequence in the context of retail industry. The empirical study examined adoption of barcoding, order processing, distribution and assembling technologies. Although Smith and Weil (2005) found complementary effects of multiple systems adoptions, the sequential nature of adoption could not be completely examined due to the limitations of the data. Battisti et al. (2004) investigated joint adoption of IT equipment and innovative work practices in Italian metalworking plants. These studies found that complementarity increases the probability of adoption of these technologies. However, none of these prior works directly address business process boundary issues in the sequential adoption of complementary technologies.

With an intention to develop an understanding of the effect of business processes on the adoption of complementary systems, two patterns of adoption are proposed as outcomes of operational and organizational influences. Organizational influences refer to factors such as organizational structure, politics and culture. Operational influences refer to variance and cost control through automation and integration. The process of medication management in the hospital setting and its associated information systems are used to test the proposed sequences. Healthcare and hospitals provide a rich basis for the study of adoption of complementary technologies since the underlying business and decisional processes are tightly integrated. The process of ordering a drug, verifying the order, dispensing the order and administering the order are well-defined and consistent across hospitals for patient safety and regulatory reasons. This homogeneity in the business process makes it possible to test whether organizational or operational themes drive adoption decisions across different facilities.

This chapter addresses the first research question: Does the order of automation of the tasks in the process have an effect on cost outcomes? Answering this question requires exploring differences in technology adoption patterns in a healthcare setting and to explore the relationship adoption patterns may have with financial performance. Sequence analysis, as described in Brzinsky-Fay (2005), is required to analyze different patterns of information systems adoption. This type of analysis provides a new and useful perspective and insight into how the order of adoption matters. Insights can be gleaned in relationship to healthcare IT adoption and the organizational fit of long-term IT strategy.

The next section of this study will build models and patterns of adoption of interrelated technology based on the literature. These models are then tested against data from the Healthcare industry. Finally limitations of this research and the pathway for future research on the patterns of adoption of interrelated business processes are discussed.

3.2. Patterns for Adoption of Complementary Systems

To provide a better understanding of the complementarities that exist within a business process context in this section, patterns stemming from operational and organizational perspectives are described. Subsequently, how the generalized adoption pattern can manifest in the clinical care process context of hospitals is discussed.

As in any industry context, IT adoption in healthcare cannot be fully understood without considering the context of the business processes that it is intended to support. Clinical processes in hospitals are very complex due to organizational realities. Typically, IT systems that support clinical processes span across several different departments and stakeholders, including administration, nursing, physicians, and pharmacy, laboratory, radiology, and others. These units differ in skill sets, experience, motivation and organizational power. Most importantly, the autonomy enjoyed by physicians and by some nurses can dictate how significant changes in clinical processes can be introduced in hospitals. While this situation is not unlike how stakeholders may interact in other industries, there is one important distinction: despite the outward differences across facilities, the fundamental business process flow of a clinical process is largely similar across hospitals. This distinction is actually beneficial when one attempts to examine adoption patterns in business process contexts.

A mechanistic perspective on IT adoption in business processes implies a focus on task automation primarily intended to address time and cost savings (Hammer and Champy 1993, Klein 1995, Peppard and Rowland 1995). However, both practitioners and academics also advocate the realignment of roles and responsibilities and organizational structures as other enablers of process improvement (Hammer and Champy 1993, Rupp and Russel 1994, Buzacott 1996). More importantly, these two orientations are not mutually exclusive. Yet, given the organizational complexities and stakeholder involvement, business process transformation and IT adoptions often are messy affairs with uncertain outcomes. The following section reviews the research literature to characterize IT enabled business process transformations from organizational and operational perspectives.

3.2.1. Patterns of Adoption from an Organizational Perspective

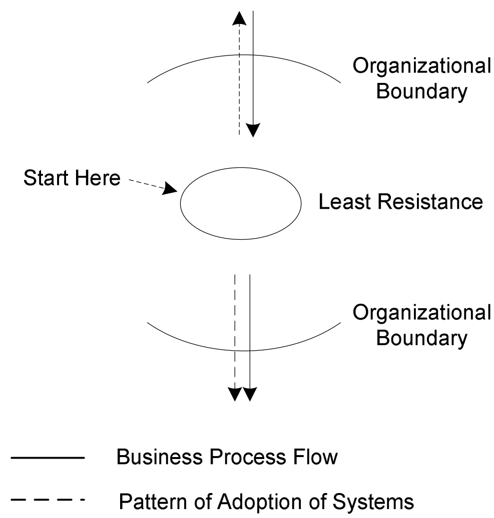
Since IT innovations often alter the underlying structure and rules of a business process, they can contribute to significant change in the balance and distribution of power within the organization. As a result, organizational politics and power become significant factors in the adoption of IT innovations into organizations (Markus 1983). To alleviate the power struggles, organizations may decide to limit the structure and attributes of information systems; but unintended consequences may still cause information systems to affect the structure and characteristics of the organization (Markus and Robey 1988). More importantly, managers find it more difficult to implement systems or interfaces between systems that cut across organizational boundaries than to implement systems that cross no organizational boundaries.

As discussed in chapter 2, organizational factors influence the business process and how systems interact and are adopted within that process. Markus (1983) argues that the political view in relation to information systems is most relevant when (1) stakeholders disagree on the nature of the problem, (2) stakeholders disagree about the ability of the system to solve the problem and (3) power is valued and scarce. Disagreements on the nature of the problem, disagreement on the ability of the system to solve the problem and power struggles are more likely to occur when managers and decision makers belong to different organizational units. Different organizational units have different purposes, perspectives and challenges. Thus, it is more likely that power struggles and disagreement will exist when decisions are made between organizational units than when they are made within an organizational unit.

When organizational forces of power and politics are strong, organizations are more likely to first adopt systems that do not cross organizational boundaries. This model is named the organization model. The organization model takes the path of least organizational resistance to the implementation of systems around a business process. Taking the path of least organizational resistance means that organizations may ignore innovation dependencies and synergies in favor of ease of implementation and organizational costs. For example, a system that is completely contained within a department and is used only for internal processing is likely under full control of the department. This internal system will be much easier to implement than one that interfaces with people, systems, and processes outside of the department or organization. Therefore, an organization or organizational unit will implement innovations in the internal stages of business processes first and then push them out. Hence, the organizational model suggests that patterns of adoption should be more rapid within internal departments than in systems where organizational boundaries are crossed.

Proposition (P1). *Organizations are more likely to adopt systems that do not cross organizational boundaries before adopting systems that cross organizational boundaries.*

Figure 1 Organizational Model of Adoption



3.2.2. Patterns of Adoption from an Operational Perspective

When business processes create an environment for synergies and complementarities between systems, substantial efficiencies can be gleaned from automating business processes in certain patterns. These synergies and complementarities come from both the relationship of IT innovations in sequential stages of a business process and from the general need to integrate systems in a business environment. These two effects are treated individually below.

An operations view on adoption of IT innovations produces patterns that focus on improving efficiency and on reducing cost and variance. This perspective is most useful when systems are used to reduce variation, increase or improve output, or decrease costs. The Theory of Constraints (see Chapter 2) presented by Goldratt and Cox (1984) applies in this situation and has two implications. First, a firm will look to bottlenecks or points of excessive variation in the process to start automation. Second, more efficiency is gained by reducing variation at the beginning of the process than at the end of the process. It is useful to discuss bottlenecks and points of excessive variation only in the context of specific processes. This view is consistent with that of (Hammer and Champy) where recognition of the end-to-end business process flow is considered as an essential first step before business process change and IT interventions are even considered.

When variation is produced at each stage or station of the business process, sequential automation is often the most effective at reducing variation and lowering costs. Again, referring to the Theory of Constraints (Goldratt and Cox 1984), out-of-bounds variation at the early stages of a process will cause subsequent stages to wait for acceptable output. This process of waiting is multiplied as each station introduces variation. Variation in business processes also tends to have a bullwhip effect, especially when those processes include imperfect information and forecasting. Therefore, reducing variation in the beginning stages of a business process will have a greater effect in decreasing the overall variation of a business process than will decreasing variation in the final stages of a business process.

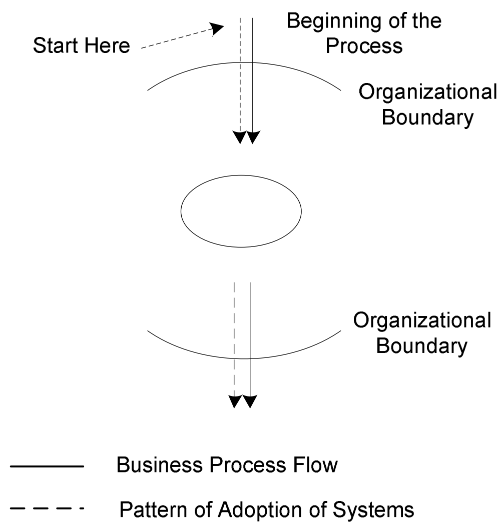
Variation in outputs at each stage of the process provides another reason for sequential implementation of systems from the start of the process to the end. If mechanisms are not in place to recognize out-of- bounds variation quickly, poor output will be passed from one stage to another. Subsequent stations will spend resources processing information or output that will not be acceptable in reaching the final business goals of the process. Hence the resources are wasted. The adage of "garbage in, garbage out" fits well here.

Because the operational view of IT adoption sees the innovations as dependent on one another, one more argument becomes relevant for sequential adoption of innovations. If the relevant systems integrate with each other, interfaces often need to be developed or set up between systems. These interfaces are expensive to create and test. If systems are implemented in order, the number of interfaces to create for each system is minimized. If systems are implemented out of order, interfaces will need to be created for each system's current environment (either human interfaces or ad-hoc temporary solutions). Later, when the whole process is automated those interfaces will have to be abandoned and new interfaces implemented for the new environment. This argument is based on the assumption that systems in the business process integrate with each other.

Considering the effects of variation, variation detection and interface implementation costs, it is predicted that automating a process sequentially from the beginning of the process to the end is effective at reducing costs, improving output and reaching business goals. This assertion is made with the recognition that in the presence of bottlenecks and points of unusual variation, order of adoption will vary. This perspective is labeled the operational model.

Proposition (P2). *Sequence of systems adoption is likely to reflect the temporal ordering of the business process steps.*

Figure 2 Operational Model of Adoption



3.2.3. Potential Impacts of Operational and Organizational Models on Financial Outcomes

Because the organizational model of adoption focuses on appeasing political actors and the operations model of adoption is focused on reducing variance and improving quality and efficiency in an end-to-end business process flow, performance implications manifest in both instances. Where political actors are powerful, an organization may find the savings of appeasing these actors greater than the benefits provided by following an operational model of adoption. When this is the case, more organizational adoption is expected as well as lower costs associated with the organizational model of adoption than with the operational model of adoption. In other cases, political actors may not have the power to use financial resources or create inefficiencies to oppose system adoption. In these cases, savings accrued from following an operational model of adoption are likely to be greater than those generated by appeasing the political actors. Subsequently, lower costs should be associated with the operational model of adoption than with the organizational model of adoption.

The conflict between operational and organizational models of adoption is highly relevant in the healthcare context. In healthcare organizations it is likely that stakeholders exert influence on how technologies are adopted. This is especially so in the case of physicians, who have considerable autonomy in their interactions with hospitals. In many cases, physicians are affiliated with hospitals and not directly employed. Nurses and pharmacists also exert considerable influence in adoption processes. It is well documented that nurses can create workarounds in clinical processes to adapt to the introduction of technology in their processes (Tucker and Spear 2006). Workarounds can create inefficiencies in the care process that would ultimately impact organizational performance.

Based on issues detailed for the organizational and operational processes, it is proposed that there are organizational performance implications from IT adoption in business processes:

Proposition (P3). *Different models of technology adoption are associated with dissimilar financial outcomes.*

These three propositions are tested in the context of medication process. The next section describes the context and examination of the operational and organizational models of adoption.

3.3. The Medication Management Process

This study focuses on the healthcare industry and, in particular, the business processes associated with medication prescribing and dispensing within a hospital. The medication process within hospitals is an issue of significant interest to policymakers and managers. Strong evidence has documented high rates of medication errors resulting from the wrong drug or dosage administered to patients (Burlton 2001). Information technology is widely viewed as an essential tool to improve medication safety by automating these business processes (Bates and Gawande 2003).

To understand complementarities and synergies created for IT innovations in this context, the main hospital pharmacy process is first discussed. This process is also described in Bates (2000) and focuses on the core of the business process and on the systems connected to administering medications and monitoring patients. The analysis focuses on the core process of creating the order to producing and delivering the packaged prescription to the clinician (see Figure 4). As such, medication process in this study is defined as the ordering of drugs for the patient, the recording of information needed for the pharmacist, pharmacy activities to verify and dispense the prescription, and administering the medication.

Each patient in the medication process is associated with a physician or group of physicians. The physicians visit the patients and order interventions and medications to treat the patient's conditions. The nurses on the floor attend to patient's needs and implement the doctor's orders. When physician orders include medications, the pharmacy fills the prescription and the nurses administer medications to the patient. Many prescriptions (especially dangerous and addictive drugs) are well-secured and have specific procedures involved in their dispensing to ensure they are used only in the manner prescribed by the physician.

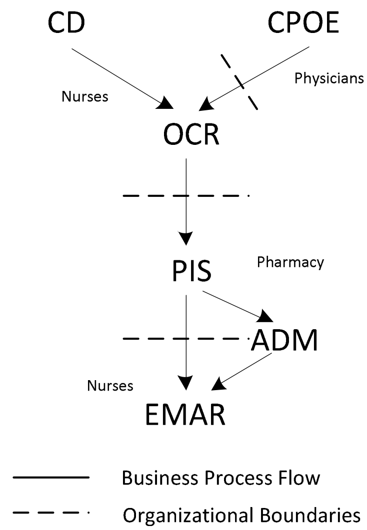
Through the normal course of a day, the nurses add notes to the medical chart describing assessments, interventions (including medications), and the response of the patient.

When pharmacies receive physicians' orders they check the orders against the patient's charts and records to avoid any adverse effects such as drug interactions or allergic reactions. If the prescription meets the pharmacist's standards, the order is then processed. In most hospitals, processing the order involves inventory management practices such as verification that the medication is stocked, noting medications to reorder, and removing the medication from inventory. The medication is measured and mixed or counted in the pharmacy. The medication is then packaged and sent to the floor nurses for administration. Variations in this process can occur for several reasons. For instance, instead of keeping all inventory in the pharmacy some medications may be kept in automated dispensing machines on the unit floor. Nurses have access to this unit as granted by the pharmacy. The dispenser records who opened the unit, how long it was open and how much medication was taken.

From an organizational perspective this process involves three distinct groups with complementary tasks: physicians prescribe, pharmacists dispense, and nurses administer medications and record effects. Information systems supporting these groups are typically defined within functional boundaries. Additional systems are needed to span organizational boundaries and connect the business processes represented by these groups in an end-to-end fashion. From an operational perspective the medication process can be viewed as a series of tasks initiated by inputs from physicians and nurses, and verification of these inputs before dispensation of medications by the pharmacist.

Six complementary systems that support the three-stage process of prescribing, dispensing, and administration (see Figure 3) are included in this study. The process begins with the physician's prescription, which generates an "order" for the pharmacy to prepare the medication. The order can be generated either by nurses in the Order Communication and Results (OCR) system or by physicians in a Computerized Physician Order Entry (CPOE) system. The CPOE system requires greater involvement of physicians in the process since it requires direct inputs on a computer or hand-held device. In contrast to nurses, it is important to note that physicians are not typically hospital employees and usually work outside of the organizational boundaries of the hospital. Both OCR and CPOE can be integrated with the Clinical Documentation (CD) system, which provides an electronic version of patient's care plan including their medication schedule. Thus, CD helps to facilitate the ordering of medications.

Figure 3 The Medication Management Process and Systems



The second stage of the process is dispensing of the medication by the pharmacy. The Pharmacy Information System (PIS) receives an electronic order from OCR or CPOE, which provides the pharmacist with the information needed for verifying and dispensing medications. PIS can potentially manage pharmacy inventory and process prescriptions from receipt of the order to dispensing the drug. PIS is used within the pharmacy department and does not cross organizational boundaries. For some medications such as controlled substances, automated dispensing machines (ADM) may be kept on the unit floors. The pharmacy stocks and controls these devices. The nurses are able to retrieve medications from the ADM when properly authenticated. Finally, the administration of the medication is recorded in the electronic medication administration record (EMAR). Because this study focuses on the core operations of the medication management process, several supplementary systems are related to this context such as computerized patient records, clinical decision support, robot technology for dispensing, and bar coding.

To apply the operational and organizational models to the medication management process, the characteristics of the process and organizational environment around the process must be discussed. The operational model of adoption as defined earlier is based on the process sequence. As indicated in Figure 3, there are potentially two starting points for this sequence represented by CD or CPOE. In the case of organizational model of adoption, the process boundaries define the theorized sequences. The three stakeholder groups – nurses, physicians and pharmacists – define the organizational boundaries. While adoption can be initiated by any of the stakeholders, organizational realities (Markus 1983) would suggest that Physicians will be the most resistant to IT adoption. Though CPOE creates efficiencies for the nurses and hospital staff, physicians often find typing orders into the computer more cumbersome than writing a few lines of orders into the chart. In addition, physicians find CPOE inconvenient because the computer interface is rarely in your pocket or at your fingertips while you talk with the patient; although, in recent years it has become more common. CPOE also requires the doctor to log into the system and remember yet another password. The effects of these issues are increased by the fact that most doctors are not directly employed by the hospital. For this reason it is proposed that the CPOE will consistently appear last in the adoption sequence. Though nurses input information into EMAR, physicians are required to interact with the system. Therefore, it is predicted that CPOE and the EMAR will be the most difficult adopt. Given that nurses and pharmacists are employed by the hospitals, it is less likely that they will be able to resist process changes, even when the systems could increase the complexity of their work. However, if crossing organizational boundaries is more difficult than working within a single organization, OCR and ADM would be more difficult to adopt than would PIS and CD. Therefore, the following four distinct sequences for the operations model of adoption and four distinct sequences for the organizational model of adoption are defined (see Table 3).

Table 3 Operational and Organizational Reference Sequences

Model	Order of Adoption					
	1	2	3	4	5	6
Operational Patterns	CPOE	CD	OCR	PIS	ADM	EMAR
	CD	CPOE	OCR	PIS	ADM	EMAR
	CPOE	CD	OCR	PIS	EMAR	
	CD	CPOE	OCR	PIS	EMAR	
Organizational Patterns	CD	PIS	OCR	ADM	EMAR	CPOE
	PIS	CD	OCR	ADM	EMAR	CPOE
	CD	PIS	ADM	OCR	EMAR	CPOE
	PIS	CD	ADM	OCR	EMAR	CPOE

To test the financial proposition, operational costs, operational revenue, and net income per patient day are used. Dividing net income and operational costs by patient day standardizes the measure across hospitals of varying sizes. The medication management process spans multiple organizational units and political actors. This fact makes the use of individual costs estimates, such as pharmacy salaries or nursing salaries, difficult to use. Many doctors are not paid by the hospital. Many costs of organizational adaptation will occur in unpredictable places such as concessions offered to one party to adopt the system, which may be unrelated to the system itself. Therefore, hospital operational costs are the closest financial predictor to the costs associated with the medication management process. However, operational costs only describe part of the picture. Increased costs may be justified if increased revenues are larger. Therefore, operating revenue and net income are also included.

3.4. Data and Analysis

Hospital pharmacies are an excellent context for this work. An empirical study of complementary IT systems adoption requires a multi-year dataset that spans an entire industry. Additionally, given the business process context of this study, regulation of medication prescription and administration provides a common understanding of the business processes involved. The dataset used in this study provides a unique opportunity where both the above requirements are met. To evaluate the organizational and operational influences on the sequence of IT adoption, the theorized sequences are evaluated for the two orientations using a sequence analysis method developed in the sociology and genetics contexts (Abbott and Hrycak 1990). The effect of each orientation on hospital financial outcomes is tested.

3.4.1. Data Sources

The adoption data is constructed from the 1998-2007 HIMSS Analytics database. The HIMSS database provides information on which systems were adopted by each hospital. In many cases, there is also information on the year each system was adopted. When contract date and implementation information is not available in any database, it is possible to determine in exactly what year the system was adopted by looking at the automation status provided by each database. When it is not possible to determine the exact year of adoption, the hospital is dropped from the sample as this analysis depends on an accurate description of the order of adoption. The adoption data had to be further reduced by removing observations in which a hospital adopted more than one of the systems of interest in a single year. This final factor is the largest limiting factor on the sample size.

Table 4 Descriptive Statistics and Population-Sample Comparison

	AHA Population	Sample
N	6312	135
Beds	156(181)	189(162)
Medicare Payer Mix	44.18(20.52)	46.04(12.82)
Medicaid Payer Mix	15.16(11.94)	17.03(9.84)
Technical Index	2.56(2.37)	3.4(2.33)
JCAHO	71.4%	79.3%
Not-For-Profit	50.1%	75.6%
For-Profit	23.8%	6.7%
Government	26.2%	17.8%
System Member	55.1%	70.4%
COTH Membership	5.8%	8.1%
Assoc. w/Med school	23.2%	28.9%
Metro Area	64.6%	64.4%
Micro Area	15.5%	21.5%
Rural Area	19.8%	14.1%
System Count *	---	4.27(1.04)
Operational Distance	---	0.748(0.149)
Organizational Distance	---	0.380(0.204)

* Only includes a count of the six systems of interest.

Hospital characteristics and financial data on net income, operating revenues, and operating expenses were collected from databases for the year 2007 provided by the American Hospital Association and the Center for Medicare and Medicaid Services. Bias in hospital demographics is due to the fact that only hospitals with sequential adoption of medication management systems may be included. The sample represents hospitals which are on average larger than the national average. Hospitals in the sample provide more services (represented by the technical index), are more often not-for-profit and are more likely to be a member of a multiple hospital system (see Table 4).

3.4.2. Event Sequence Analysis

The need for defining event sequences arises in many social and scientific studies (Brzinsky-Fay et al. 2005). Sequence ordering allows one to investigate the influence of variables in the sequences and whether a specific pattern of events exists in the data (Abbott and Hrycak 1990). It has been used in natural and social sciences including analysis of DNA sequences (Needleman and Wunsch 1970), study of ritual dances (Abbott and Forrest 1986) and the study of careers of 18^{th} century musicians (Abbott and Hrycak 1990). In this research context, sequence ordering of IT adoption is temporal and discrete. Each event in the sequence signifies the adoption of an IT system in the process.

Sequence construction and comparison requires the use of dynamic programming methods to calculate the distances between sequences. This study uses the sq package in Stata to calculate distances between patterns. The sq package is described in Brzinsky-Fay et al (2005). This package calculates the Levenshtein distance between two sequences. The Levenshtein distance was first developed to calculate the distance between two strings of characters (Levenshtein 1966).

The Levenshtein distance calculates the number of operations (insertions and deletions) to transform one sequence into another. As applied in this context, the maximum number of operations to transform any sequence is six. The count of operations for each hospital is then standardized to a scale of 0 to 1. This means that each operation increases the distance by 0.1667. The context of systems adoption requires that different lengths of the sequence be accounted for. Therefore difference was calculated between the first four systems of a given adoption model and the hospital's adoption path if the hospital had only adopted 4 systems. The implication of this is that if the hospital has followed the adoption model perfectly to this point, their score would be 0. It is, therefore, important to include the system count and an interaction term between system count and the adoption model distance in the regression.

Calculating an example distance requires a reference pattern (from the operational model) and a pattern followed by several hospitals in the sample:

Sample Pattern: PIS → CD →OCR → ADM → EMAR → CPOE

Reference Pattern: CD → CPOE → OCR → PIS → ADM → EMAR

In the reference pattern CD should occur first and PIS should occur after CD and OCR. This can be done with one deletion and one insertion.

Form after step 1: CD →OCR → PIS → ADM → EMAR → CPOE

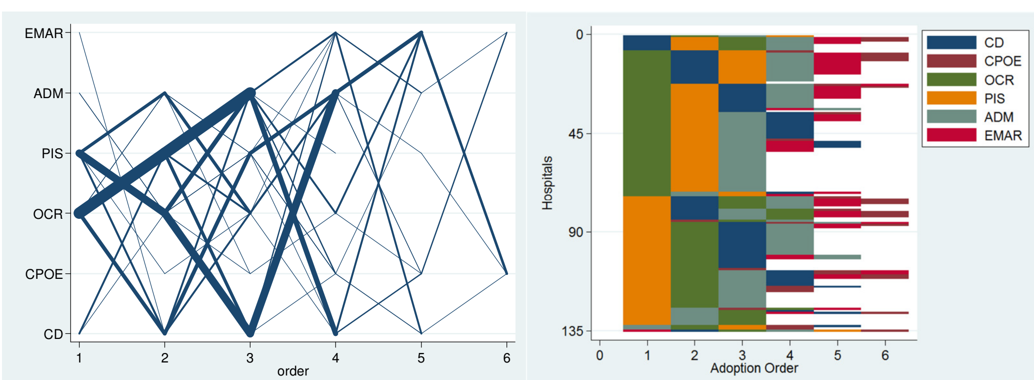
Further, CPOE should occur before PIS and not at the end of the sequence. This can again be corrected with one deletion and one insertion.

Form after step 2: CD → CPOE → OCR → PIS → ADM → EMAR

After two insertions and two deletions, the sample pattern now matches the reference pattern for a total of four operations. Given that the greatest distance between any hospitals pattern of adoption and the reference patterns was six, the hospital would receive a distance to this reference of 4/6=0.667.

To complete the analysis, the data must be shaped into long form with each record containing the hospital identifier, the name of the system which was adopted and the order in which that system falls. Because not all hospitals have adopted all systems, there are fewer than six records for most hospitals. To ensure that the hospital's adoption pattern was a path, only hospitals which had adopted three or more systems were included in the data set. After processing the data through the sq package, it can then be transformed back to short form and analyzed with traditional statistical tools. Each model of adoption describes multiple possible patterns. To account for these differences, the Levenshtein distance was calculated for each hospital against all possible patterns. The smallest distance from the operational model was then used as the measure of the operational distance. The same was done for the operational distance.

Figure 4 Visualizations of Adoption Pattern Variance



Further, it is noted that if a hospital was following the operation or organizational model, but had not completed the sequence, they received a perfect score. The subsequent regression should, therefore, account for the number of systems adopted and for a potential interaction between the distance measure and the number of systems the hospital had adopted. The data contain 52 different adoption patterns. The most common pattern of adoption is OCR, PIS, then ADM. (see Table 5 and Figure 4).

Table 5 Five Most Common Patterns of Adoption

Sequence-Pattern	Freq.
OCR→PIS→ADM	18
PIS→OCR→CD→ADM	12
OCR→PIS→ADM→CD	8
PIS→OCR→ADM	7
OCR→CD→PIS→ADM→EMAR	6

The number of applications of interest adopted by the hospital provides a normal distribution. This suggests that hospitals are at a variety of different stages in the adoption process. The six systems in this study provide a range of characteristics. The most commonly adopted system is PIS followed by OCR. The relative diffusion of these applications may have to do with the age of the innovation. The earliest adoption of CPOE is nine years after the earliest adoption of the next newest technology. The earliest contracts for all of the other technologies are from the 1970s.

In this context, sequence analysis provides a standard measure for how close each hospitals adoption path is to the operational and organizational models of adoption. This method provides a novel and valuable perspective through which the adoption of a set of systems can be viewed. Using traditional methods, it is impossible to differentiate between two hospitals which currently may have the same application set, but had come to this point in different paths. Sequence analysis makes it possible to look at the effects of different paths of adoption.

3.5. Results

Descriptive statistics of the operational and organizational distances show that hospitals are more likely to follow the organizational model of adoption. On average the Levenshtein distance from the organizational model is only 0.380 as compared to the 0.748 distance from the operational model. Operational and organizational distances showed no evidence of correlation (Pearson coefficient < 0.01). This suggests that the two patterns (or sets of patterns) are significantly different from one another. A low correlation coefficient also suggests that both patterns may be included in the same model. It is noted that from this point forward the distance measures have been reversed for ease of interpretation (1-operational distance = operational measure). The underlying theory suggests that these measures might be correlated with organizational size. This prediction is not well supported. It is true that larger hospitals were less likely to follow an operational pattern (Pearson coefficient of 0.090); nevertheless, it is not a strong correlation. The relationship between the organizational pattern and the size of the hospital was much smaller (< 0.01).

Because of the presence of outliers a weighted least squares regression was used (see Table 6). This method is an iterative process which puts less weight on observations which dramatically change the coefficients. Both net income and operating costs were divided by the number of patient days for each hospital. This gives an estimate of hospital net income, operating costs, and operating revenue per day each patient is in the hospital. Because operating costs are theoretically closer to the expected outcomes of automating the medication management process, it was expected that the R-squared would be higher than for net income or operating revenue.

Table 6 Robust Regressions on Net Income, Operating Cost, and Operating Revenue

DV	Adjusted Net Income	Adjusted Operating Expense	Adjusted Operating Revenue
Operational Measure	-1441.67 ***	-2558.80	-3860.94 **
Operational * Sys Count	314.79 ***	452.61	750.34 **
Organizational Measure	1108.71 ***	2941.73 *	2904.79 *
Organizational * Sys Count	-231.26 ***	-604.71 *	-587.23 *
System Count	110.94 *	307.07	213.80
Ln(Beds)	8.57	-59.79	-33.29
Medicare Payer Mix	-5.51 ***	-15.34 ***	-17.43 ***
Medicaid Payer Mix	-3.31 **	-6.99	-10.43
Technical Index	-0.92	33.16	33.41
JCAHO Accreditation	-25.07	342.39 **	450.44 ***
Government	3.32	-171.68	-317.41 **
For-Profit	-21.28	-313.88	-237.15
System Member	57.60 *	344.23 ***	422.83 ***
COTH Member	66.17	644.82 ***	723.81 ***
Assoc. w/Medschool	23.35	88.80	94.79
Rural Location	44.23	-218.31	15.38
Constant	-166.05	705.05	974.56
N	135	135	135
F(16,118)	4.70	6.52	8.50
Prob > F	0.00	0.00	0.00
R-square	0.2587	0.3716	0.4278

Note: *** p<0.01, ** p<0.05, * p<0.10

The standard control variables used in relation to hospital financial outcomes show significance. Higher Medicare payer mix is associated with lower net income, operating expense and operating revenue per patient day. JCAHO accredited hospitals incur more costs, but have higher compensating revenues. Being a member of system of hospitals or a COTH member has a similar effect.

Coefficients on the net income variables are more significant than those on operating cost and operating revenue. Following an operational model is related to negative movements in net income. That negative relationship is reduced as the hospital continues on the adoption path. The opposite is true of the relationship between the organizational measure and net income. In the above regressions, each of the models showed significant differences in the effect of the operational measure and the organizational measure. The p-value for the difference between organizational and operational measures in the net income regression was < 0.01. In the operating expense regression the p-value was 0.02. In the operating revenue regression the p-value was < 0.01. Therefore proposition 3 is supported. The organizational model is positively correlated with net income and operating revenue. The operational model is negatively associated with operating expense. If net income is considered inclusive of operating revenue and operating expense, the organizational model is related to a more desirable financial outcome in this context.

3.6. Discussion

There are differences in financial performance related to hospitals which have followed an organizational versus the operational model of adoption. In this context P3 is supported. Proposition three states that hospitals which follow different adoption models will be associated with different financial outcomes. In particular, hospitals that follow an organizational pattern of adoption are associated with improved financial outcomes.

The secondary effect is also interesting. There is a negative relationship between compliance with the operational model and the financial measures. This relationship is reduced as a hospital moves along the adoption path. The analysis also shows that the positive relationship between compliance with the organizational model and the financial measures is reduced as a hospital moves along the path of adoption. That is to say that the marginal benefit of adopting each system in an organizational adoption model is incrementally smaller. This could be seen as diminishing returns on investment. It could also be interpreted that the systems inside organizational boundaries have a stronger relationship with financial measures than do the final systems which span boundaries.

The analysis does not suggest there is a causal relationship between the adoption patterns and financial outcomes. However, the R-square of 0.43 is unexpectedly high given that the medication management process is only one process of many in the hospital. Because the financial outcomes are general to the whole hospital, an R-square less than 0.15 would be more reasonable. Because the R-square is high, the influence of other factors is suspect. It is likely that other factors such as management's willingness to keep employees satisfied is related to the organizational measure of adoption. Any discussion of possible relationships can be complicated and nuanced. It might be that adoption according to an operational manner helps to reduce operating costs. However, in an environment such as the hospital, keeping the employees satisfied has a significant impact on demand for services at a given hospital. Such ideas must be tested further by studies designed to test causal relationships.

The analysis also shows that the adoption patterns of hospitals in this sample are closer to the organizational model of adoption than to the operational model of adoption. Several actors in the medication management process have significant political power. Physicians are not often employed by the hospital. Hospitals must comply with the manner in which physicians wish to work (to some extent) or the physicians can take their patients to another facility. Further research on the effect of adoption patterns should study a business process in which politics and power are not as much a part of the decision process.

Although sequence analysis is a powerful tool in studying the order of adoption, the measure and analysis not a perfect fit for this context. Over 1000 observations had to be dropped from the sample because more than one system was adopted in a single year. Although much development work still has to be done, other types of analysis may be more suited to this data.

3.7. Key findings and insights of chapter 3

Using business process and operations management literature and organizational theory an operational model of adoption is proposed which prioritizes system adoption based on business process requirements. Next, with organizational theory and information systems literature as a basis, an organizational model of adoption is developed which prioritizes system adoption to fit organizational structure and politics. These competing models provide two perspectives often considered when explaining IT adoption in organizations. While the two patterns are not mutually exclusive, they are distinct in their orientation and implications related to the pattern of adoption of medication management systems. The analysis suggests that in hospitals the organizational model tends to be the more significant explanation for complementary IT systems adoption.

This study leverages event sequence analysis to study the path of adoption of a set of systems. Sequence analysis is used to calculate distances between actual adoption patterns and the theorized operational and organizational adoption patterns. The analysis provides evidence that different paths of adoption are related to different financial outcomes. In the hospital environment following the operational model of adoption is associated with lower operating expenses. However, following the organizational model of adoption is associated with higher operating revenue and higher net income.

The empirical work in chapter 4 continues to develop the idea of the interdependence of a set of systems within a process. Chapter three has clearly shown that a relationship exists between the order of automation and cost variables on a high level. An important assumption of the analysis in chapter 3 is that the medication management systems are working together and are interdependent. Chapter 4 investigates the interdependence of these systems by focusing on process level continuity and discontinuity.

Chapter 4. Automation Discontinuity in the Business Process

4.1. Introduction

The previous chapter showed that the order of automation of the tasks of the medication management process has financial impacts on the hospital level. The hospital level perspective is important because the process involves so many participants. Nevertheless, the theory also suggests that the strongest effects related to cost and quality should be seen at the process level. This chapter brings the process level outcomes into focus. The analysis of the previous chapter suggests that complementarities among systems do exist. This chapter investigates these complementarities more closely by testing the effects of continuous and discontinuous automation.

As discussed in chapters 1 and 2, business processes are not always automated in a continuous fashion. This study addresses the question: Does automation continuity or discontinuity of the business process have an impact on cost and quality? For whatever reason, information systems implementation often deviates from the process enablement objective. When systems implementations in process workflow are not continuous, they can create coordination complexities. There is much uncertainty in understanding how gaps in automation affect performance and where to expect the benefits or costs of automation. In this study, theory is tested and developed which suggests that discontinuous automation is associated with higher costs and lower quality. Further, the analysis shows that automation at the beginning of the process is associated with lower labor costs than automation at the end of the process.

Research evidence regarding the effect of continuous process automation on process quality and efficiency is scarce. Continuous automation refers to automating groups of systems in close workflow proximity. Although theory and anecdotal evidence suggests that continuous automation would have beneficial effects, empirical literature has left this question largely untouched. The information systems literature has recognized the need to study the relationship between information systems and business processes (Barua and Whinston 1998, Devaraj and Kohli 2000). The challenges of coordination inherent in organizational processes have also been well documented in the information systems literature (Malone 1987, Mumford 1994, Teng et al. 1994, Raghu et al. 2004). Several studies on the performance synergies of information systems and innovations have investigated investments in related technologies (e.g. Wozniak 1984, Golob and Regan 2002). However, most of these studies have examined adoptions of only pairs of innovations. A few studies have explored the relationships among several innovations, although they do not explicitly explore the business process synergies inherent in those innovations (e.g. Colombo and Mosconi 1995, Smith and Weil 2005). Given that information systems are implemented to enable business processes, the business process can provide the context to understand the synergies between systems. Therefore, developing knowledge of performance impacts of process automation in a business process can enrich understanding of the impact of information systems in organizations.

The empirical context for this work is the medication management process in acute care hospitals. The context of acute care hospitals is significant from both policy and managerial perspectives. Significant increases in healthcare costs have been recognized as a major risk for U.S. economic growth. Along with policy changes to health insurance and Medicare systems, health information technology (HIT) is expected to provide relief to spiraling healthcare costs and quality problems in the healthcare system. To motivate hospitals to adopt and use HIT, the Medicare Meaningful Use (MU) program was announced through the HITECH Act of 2010. This part of the act provides financial incentives for hospitals to implement and use HIT. A major component of achieving meaningful use depends on medication management process automation. Although the data for this research comes from years prior to the HITECH Act, it provides insights on the potential impacts of the meaningful use rule in hospitals that have attempted to automate the medication management process in the past decade.

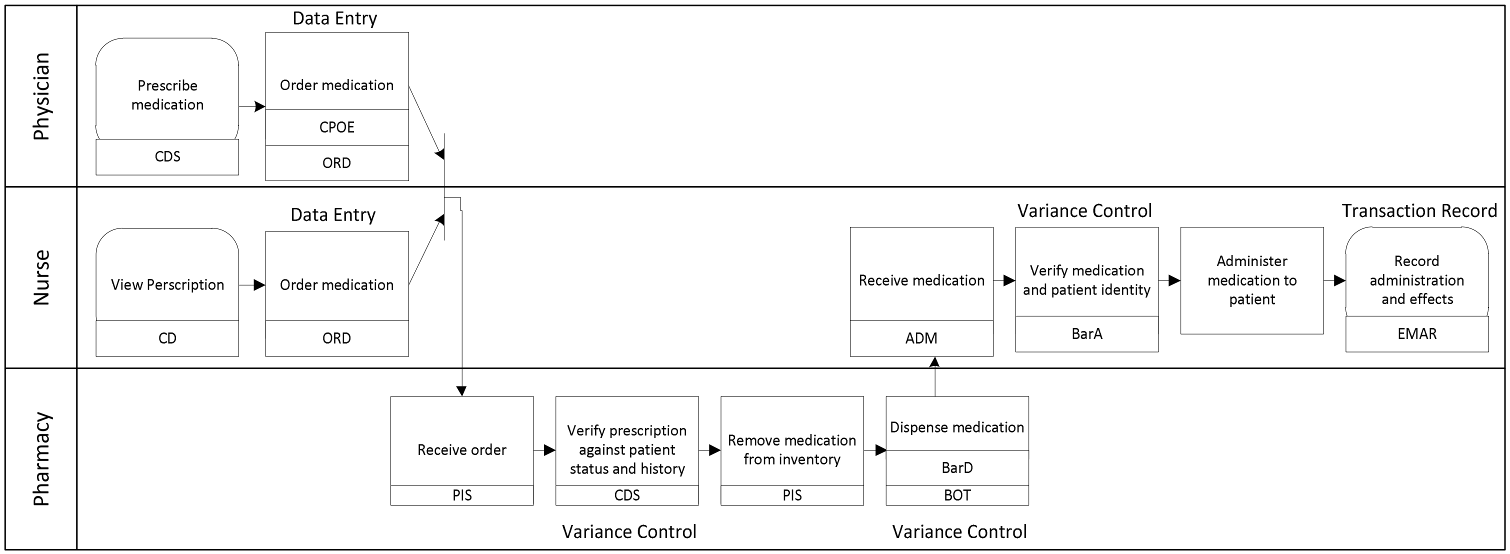
The rest of the chapter is organized as follows. Section 2 develops hypotheses based on that theory. Section 3 presents the data methods. Section 4 provides the analysis. Sections 5 and 6 discuss results, future research, and conclusions.

4.2. Context and Hypotheses

Hospital pharmacies provide an environment well suited to the study of the effects of systems interactions. The lack of uniformity in process definition and systems usage has hindered progress on empirical tests of the theoretical predictions. In this context, the healthcare industry provides an ideal setting to test these propositions. Hospitals, to a large extent, utilize similar processes and information systems for in-patient care settings. The standardization of care is mandated by government and insurance requirements. This creates a unique setting to measure the impacts of information systems on process outcomes. Further, because regulation dictates the business process, implementation of information systems within the process cannot substantially change the clinical process (i.e., patient-provider interactions). Any observations in outcomes are likely due to IT implementation and not changes to patient-provider interactions. Therefore the health-care context is used to examine the main hypotheses.

Most of the medication process systems fit within the traditional paper-based process (see Figure 5). The prescription is recorded in the Clinical Documentation (CD) system, which provides an electronic version of patient's care plan and medication schedule. The prescription is then input into the Order Communication and Results (ORD) system either manually or through integration with CPOE. The medication is then dispensed from the pharmacy inventory which can be managed by the Pharmacy Information System (PIS). Medications may also be accessed directly by the nurse if an Automated Dispensing Machine (ADM) is used to dispense medication on the unit floor. Before administering the medication, the nurse may check the identity of the patient and drug using bar-coding at administration (BarA). The event is then recorded in the electronic medication administration record (EMAR). Operationalization of the extent of automation is simply a count of the number of medication management systems which have been automated. Discontinuous automation is operationalized as the number of switches from manual to automated and automated to manual tasks in the process.

Figure 5 The Process of Prescribing, Dispensing, and Administering Medication in a Hospital with CPOE



Key

CD – Clinical Documentation
CPOE – Computerized Practitioner Order Entry
ORD – Order Communications
PIS – Pharmacy Information System
ADM – Automated Dispensing
CDS – Clinical Decision Support
BarD – Barcoding of Medications
BOT – Robot Medication Dispenser
BarA – Patient Barcoding
EMAR – Electronic Medication Administration Record

The applications used in the medication management process can be grouped by the extent to which these systems have diffused into the industry. The systems common to most hospitals include PIS, ORD, and ADM. Hospitals have the most control over pharmacy processes followed by nursing processes and finally processes that involve physicians. CDS, CD and CPOE have been adopted to a lesser degree. These systems are related to the nursing and physician activities. The final group represents newer technologies for automated inventory management and patient/medication verification techniques (BarA, BarD, BOT).

In the traditional (paper-based) process, several factors contribute to poor efficiency by causing errors in the system which need to be corrected. Human-error is the first. Though human error can happen in both automated and traditional processes, non-automated environments provide more opportunity for misreading or misinterpreting doctors' orders. Automated medication management systems provide quality checks against proven practices and statistical measures. These checks can detect typos. These systems can also provide better assurance that the drug ordered is the drug which is dispensed from the pharmacy. Pharmacy information systems, bar-codes, and robots all help to ensure that proper drug and dosage are dispensed.

Hypothesis (H1a). *Pharmacy labor costs have a negative relationship with the number of systems implemented.*

Efficiency of the medication management process is related to the costs of recording and transferring the order as well as interpretation and verification of the order against patient information and standard practices. In this process, automation should reduce nurse time in interpreting physicians' handwriting as well as time spent by administrative assistants sending the order to the pharmacy. In the long-run, the pharmacy should require less personnel hours to read the order, check inventory, and verify the order against patient information and standard practices. Because nurses are involved in many activities, the percent of variance in nurse staffing due to automation of the medication management process may be smaller.

Hypothesis (H1b). *Inpatient labor costs have a negative relationship with the number of systems implemented.*

Finally, the less disjoint a process is, the fewer opportunities there are for typos and other mistakes. More variation in inputs due to a disjoint process will create more reconciliation costs. Information system support for prescribing and medication ordering tasks can enable alerts and decision support mechanisms. More importantly, continuous automation can minimize the need for repeated data entry and reconciliation errors.

Three other factors contribute to saving time through continuous automation. When mistakes are made, human resources are required to detect, evaluate, and correct the mistakes. When such boundary checks are automated, time in quality management duties should be reduced. Closely related to this issue is reconciliation error. Orders that have been entered into the system using different notations, formats, or values make the process more resource intensive. Finally, when data is captured by medication management systems, managers in the pharmacy will have better estimates of demand and current inventory and can save time in making and correcting inventory decisions. Discontinuous flow of the process may lead to inefficiencies. The more discontinuities in the information flow, the more times data will need to be reinterpreted, reentered and reconciled.

Hypothesis (H1c). *Pharmacy labor costs have a positive relationship with the number of discontinuities in the process.*

Hypothesis (H1d). *Inpatient labor costs have a positive relationship with the number of discontinuities in the process.*

Related to the factors affecting labor costs is the impact of technology adoption and labor use in business process. There is a growing body of literature that indicates that technology adoption leads to demand for higher skilled workers (Bresnahan et al. 2002). The skill-biased technical change hypothesis primarily arises from complementarities that exist between technology use and task design. Information systems can be especially useful in automating routine record keeping and decision-making tasks. For example, with the use of pharmacy information systems, pharmacists can be relieved of checking for insurance benefits, and generic substitution rules for most simple prescription fulfillment tasks. Drug utilization alerts can also streamline the more complex decisions pharmacists have to make about drug interaction effects. Automation of other simple tasks in the medication management process can also reduce the need to hire more pharmacy technicians and clerical staff. Thus, the labor mix in the business process would be biased towards higher skilled workers. However, for organizations to be more effective in task substitution and redefinition, workflow automation should be orderly. Therefore, continuous automation is more likely to enable organizations to rationalize workflow tasks within departments and realize the benefits of technology based skill change. Discontinuities on the other hand, will require more labor in data entry, quality control and reconciliation. Therefore we can predict the following relationship between automation and pharmacy labor:

Hypothesis (H2a). *Pharmacy labor mix is biased towards higher skilled workers with automation in the medication management process.*

The same arguments also apply to the relationship between automation and inpatient labor.

Hypothesis (H2b). *Inpatient labor mix is biased towards higher skilled workers with automation in the medication management process.*

Finally, discontinuity should lead to a need for lower-skilled labor in both the pharmacy and the inpatient environment to input, transfer, and verify data.

Hypothesis (H2c). *Pharmacy labor mix is biased towards higher skilled workers with continuous automation in the medication management process.*

Hypothesis (H2d). *Inpatient labor mix is biased towards higher skilled workers with continuous automation in the medication management process.*

The same arguments which apply to cost savings due to variance control also apply to improved quality due to variance control. Clinical systems built-in checks for data entry mistakes and statistical checks for outliers should lead to decreased adverse drug events.

Hypothesis (H3a). *Adverse drug events decrease with automation in the medication management process.*

Multiple order entries and parallel processes can lead to increased variation. As users find work-arounds due to the discontinuous system, further increased variation is expected. Therefore, it can be hypothesized that adverse drug events are related to the extent of automation as well as discontinuities in automation.

Hypothesis (H3b). *Adverse drug events increase with discontinuous automation in the medication management process.*

To answer the research question, each of the above hypotheses predicts a quality or cost outcome in relation to discontinuity or extent of automation. The next hypotheses consider the role of the system in the process. The following hypotheses view the interaction between systems and business process in terms of stages.

When variation is produced at each stage or station of the business process, automation at the upfront stages is often the most effective at reducing variation and lowering costs. Again, referring to the Theory of Constraints (Goldratt and Cox 1984), out-of-bounds variation at the early stages of a process will cause subsequent stages to wait for acceptable output. This process of waiting is multiplied as each station introduces variation. Variation in business processes also tends to have a bullwhip effect, especially when those processes include imperfect information and forecasting. Therefore, reducing variation in the beginning stages of a business process will have a greater effect in decreasing the overall variation of a business process than will decreasing variation in the final stages of a business process. Considering the effects of variation, variation detection and interface implementation costs, it is predicted that automating the front end of a process is the most effective at reducing costs and increasing quality.

Hypothesis (H4a). *Automation at ending stages without automation at beginning stages of the process is associated with higher pharmacy labor costs.*

Again the same effect is expected in the inpatient environment:

Hypothesis (H4b). *Automation at ending stages without automation at beginning stages of the process is associated with higher inpatient labor costs.*

4.3. Data and Model

The research question and hypotheses center on process outcomes (cost and quality) on the process-based automation factors (discontinuity and role of the system). To test these hypotheses a fixed effects panel analysis is applied to data from 341 California hospitals. In the following section the data and its sources is first described. Then the fixed effects panel model is briefly discussed.

4.3.1. Data

Data are compiled from the California Office of Statewide Health Planning and Development (OSHPD), HIMSS Analytics, and the Center for Medicare and Medicaid services (CMS). The compiled data sources required merging, testing, and correcting matches across time as well as between data sets. The sample was limited in this study to California hospitals. This is due largely to the fact that examination of the hypotheses is only possible using a reasonably long time frame for the panel data. OSHPD has collected discharge information on all California patients for over a decade. Patient discharge information makes it possible to calculated adverse drug event rates for each hospital. OSHPD data collects cost and labor rate information at a detailed level of granularity. Similar panel data on adverse drug events are not available from a national sample. While a national level data provided by CMS does provide cost information, it does not provide a similar level of granular information as the OSHPD dataset that would allow a process level breakdown of costs and labor rates. Further, the national data sets do not provide information about hourly rates for each cost center. A simple comparison of hospitals included in this study to a national sample from the annual survey of the American Hospital Association reveals a few differences (see Table 7). The California sample includes more large hospitals. The national sample includes more government owned hospitals. The case mix index (CMI) for the California sample is smaller than the index for the national sample. The CMI represents the complexity of the cases treated by each hospital. Hospitals which treat sicker patients may have slightly different cost and price structures than hospitals which treat patients who are not as sick. The California hospitals also handle more Medicaid patients. Although there are many hospitals in the national set that would match closely to the California sample, results must be interpreted with due considerations for the differences in the sample.

Table 7 Sample to Population Comparison

Variable	California Sample	National Averages
Bed Size	259	172
Medicare Patient Days	41.67%	48.22%
Medicaid Patient Days	24.33%	16.65%
Not-for-profit	64.96%	59.97%
For-profit	20.86%	16.64%
Government	13.90%	23.39%
Case Mix Index	1.126	1.337

Note: Both sets of means are calculated from full sample averages using data from 1998 to 2008. The California data set includes 2,857 observations. The national Data set includes 17,264 observations.

The data from HIMSS Analytics was compiled from over 10 years of data. Over time the HIMSS Analytics survey has evolved along with the health information technology which it surveys. Unique application names and adoption statistics were extracted for each of the systems of interest. These were then compared across years to make sure that the systems in one year are comparable to systems in all the other years. For example, clinical documentation has been called by four different names and variations of abbreviations have been used over the life of the HIMSS Analytics survey. After standardizing the HIMSS Analytics dataset, the California data was merged using Medicare IDs. The final analysis used the OSHPD ID to track hospitals over time to reduce the risk of duplication issues due to changing Medicare IDs over time.

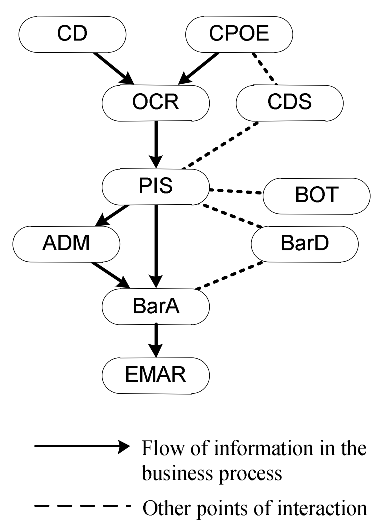
Table 8 Sample Descriptive Statistics

Variable	Mean	Std. Dev.
Bed Size	259	185
Medicare Patient Days	41.67%	17.60%
Medicaid Patient Days	24.33%	19.65%
Not-for-profit	64.96%	--
For-profit	20.86%	--
Government	13.90%	--
Case Mix Index	1.126	0.275
Pharmacy Labor Cost (per patient day)	$4.65	$6.96
Pharmacy – Calculated Hourly Rate	$37.56	$8.09
Clinical Labor Cost (per patient day)	$125.39	$91.09
Clinical Rate – Calculated Hourly Rate	$33.51	$9.67
ADE per discharge	0.109	0.058
Medication Management System Count	3.824	1.280
Number of Automation Discontinuities	2.905	1.056
Hospitals in Automation Stage 1	66.85%	--
Hospitals in Automation Stage 2a	4.31%	--
Hospitals in Automation Stage 2b	15.33%	--
Hospitals in Automation Stage 3	10.04%	--

Note: Samples are averages from the entire panel. Sample size - 2857 observations, 341 hospitals

Two approaches are taken to the independent variable for process automation. First, the state of automation is described using a count of medication management systems and the number of discontinuities in the process. Discontinuities in the business process are then operationalized as the number of interfaces between traditional paper-based systems and automated systems. Interfaces are defined by the flow of information in the business process (see Figure 6). Because measures of medication management systems and discontinuities are correlated, both the individual and joint effects are examined in the models. Second, the process automation measure is operationalized using the distinct stages of the process workflow. In labeling the stages, the adoption paths exhibited by most hospitals in the sample were followed. For instance, hospitals have traditionally lagged in adopting CPOE (entry), PIS (processing and dispensing), and EMAR (administration) into their processes. Therefore, automation of PIS was labeled as 'Stage 1', because it is generally adopted first into the process. Adoption of CPOE on the front end was labeled as 'Stage 2a,' and adoption of EMAR on the back end as 'Stage 2b.' Finally, 'Stage 3' is full automation of all three main workflow stages. A measure which counts the number of continuous systems in the process was also considered. This could be contrasted with the number of systems not in the largest continuous group of systems. However these measures had too little variation to justify using them as the basis of the analysis. This is largely due to the patterns of adoption described in the staging model.

Figure 6 Information Flow in the Medication Management Process



Adverse drug events were calculated per patient discharge using ICD-9-CM codes and external cause of injury codes. The measure included all dangerous reactions to drugs except those related to illegal drug use or self-inflicted poisoning. A full description of these codes can be obtained from the Healthcare Cost and Utilization Project (Elixhauser and Owens 2007). The number of adverse drug events per discharge was skewed. A log transformation was used to normalize the data (see Table 3).

Skill mix can be measured in several different ways. The first is a ratio of high-skilled labor to total labor. This ratio should increase as higher-skilled workers work more hours or as lower-skilled workers work less hours. The nature of the data does not support clean construction of such a variable. The second measure is the average hourly rate. Total labor costs for the pharmacy are divided by the number of hours worked by all pharmacy employees. In theory, higher-skilled labor should cost more and lead to higher hourly rates. The weakness of the hourly rate measure is that many high skilled workers are salaried. They may have to work more hours and not get paid any more. While this could lead to underestimation of the hourly rate measure, it still accurately captures the labor costs in the process.

4.3.2. Method

Fixed effects, random effects, and dynamic panel methods were all considered as feasible approaches to empirical analysis of the panel. All three of these approaches can control for hospital specific heterogeneity in different ways. The applicability of fixed effects and random effects models was first examined for the best fit. The Hausman tests showed that, in every case, the random effects model was not consistent. Therefore, the fixed effects model is implemented.

While the fixed effects model accounts for time invariant heterogeneity, it is not immune to endogeneity issues in the panel data. As a result, a dynamic panel was considered and applied as described in Holtz-Eakin et al. (1988), Arellano and Bond (1991) and Blundell and Bond (1998). A dynamic panel has the potential to account for the existence of an unobserved process which causes a correlation of the IT variables and the process outcomes. That is, potential endogeneity issues can be better addressed by a dynamic panel approach. However, two major issues arose in detecting and dealing with possible endogeneity. First, inclusion of even the most limited number of lagged general method of moments instruments led to over-identification issue, which can cause bias in estimation. Second, instruments (for the panel length) which are both sufficiently unrelated to the outcome variable and sufficiently correlated with the independent variable were unavailable for the study duration. Therefore, the dynamic panel approach was not pursued further. While the fixed effects model will adjust for unobserved hospital specific heterogeneity issues, the potential of endogeneity is acknowledged as a limitation of this study.

All dollar variables reported in the study were inflation adjusted using data from the Bureau of Labor Statistics. Producer price indexes are available for Medicare, Medicaid, and all other providers. Inflation corrections were calculated for each hospital in accordance with its patient mix. Dollar costs are therefore standardized to 2008 dollars. Salary cost variables were then standardized by dividing them by patient days. This provides a figure for the cost of pharmacy salaries for each day a patient stays in the hospital making large and small hospitals somewhat more comparable. The rate variables took all salary costs and divided them by hours worked. The distribution of pharmacy labor costs and clinical labor costs per patient day where highly skewed to the right and required log transformations. The rate variables were normal and therefore they were not log transformed.

Table 9 Dependent Variable Calculations

Variable	Calculation
PharmSalary	$\ln\left(\frac{Pharmacy\ Salary\ Cost}{Patient\ Day}\right)$
PharmRate	$\frac{Pharmacy\ Salary\ Cost}{Pharmacy\ Labor\ Hours}$
ClinSalary	$\ln\left(\frac{Clinical\ Salary\ Cost}{Patient\ Day}\right)$
ClinRate	$\frac{Clinical\ Salary\ Cost}{Clinical\ Labor\ Hours}$
ADEs	$\ln\left(\frac{Adverse\ Drug\ Events}{Discharges}\right)$

With over 2,800 observations, there is sufficient power to detect associations of practical interest. The data provide an average of 8.38 observations per hospital.

4.4. Analysis

Most variables on hospital demographics do not change over time (such as location) and are thus not included in the fixed effects model. Bed size and payer mix variables were examined for variations over the duration of the panel data. Both these variables exhibited minimal variance and therefore were excluded from the fixed effects model. The results of the fixed effects regressions are reported in Tables 10 and 11.

Table 10 Effects of Discontinuities on Cost, Efficiency, and Quality

DV	PharmSalary	PharmRate	ClinSalary	ClinRate	ADEs
mmc	0.0288 *	0.3831	-0.1227 ***	-0.9508 ***	-0.0077
dis	0.0005	-0.1529	0.0846 ***	0.5327 ***	0.0174 **
cmi	0.1346	2.4754	0.0138	1.1303	1.0196 ***
y1999	-0.0702 ***	0.1011	0.1230 ***	0.8377	-0.0187
y2000	-0.0292	1.5663 ***	0.2195 ***	2.9651 ***	0.0121
y2001	0.0239	3.1256 ***	0.3020 ***	4.3542 ***	0.0584 **
y2002	0.0986 ***	4.6426 ***	0.4794 ***	7.4818 ***	0.0642 ***
y2003	0.1669 ***	5.9343 ***	0.6196 ***	8.8856 ***	0.1225 ***
y2004	0.0900 **	7.3783 ***	0.6791 ***	10.8370 ***	0.2976 ***
y2005	0.2383 ***	7.9364 ***	0.3551 ***	8.9384 ***	0.3808 ***
y2006	0.2685 ***	8.9645 ***	0.8570 ***	13.6190 ***	0.4209 ***
y2007	0.2928 ***	8.9992 ***	0.9366 ***	14.1492 ***	0.4683 ***
y2008	0.2775 ***	9.7702 ***	0.6017 ***	10.9941 ***	0.4675 ***
_cons	1.0014 ***	28.3346 ***	4.3192 ***	26.6286 ***	-3.7180 ***
R-Sq-w	0.1825	0.4006	0.1152	0.2745	0.5439
R-Sq-b	0.1269	0.1806	0.0048	0.0596	0.4689
R-Sq-o	0.0995	0.2636	0.0492	0.1627	0.4962

Note: 2856 observations, 341 hospitals. Using robust standard errors. *** sig. at .01, ** sig. at 0.05, * sig. at 0.10

Tests of the hypotheses in the clinical environment show evidence to support the salary cost hypotheses. Salaries are significantly and negatively related to the number of medication management systems implemented in the hospital (H1b). Discontinuities in the process are significantly and positively related to clinical salary costs (H1d). It does appear that extent of automation within the process and automation discontinuities have a relationship with labor costs in the inpatient environment. However, the measures related to pharmacy do not support the hypotheses. Higher pharmacy salaries are associated with hospitals that have implemented more systems (H1a). There is no significant relationship between pharmacy salaries and the number of automation discontinuities (H1c).

Further, the pharmacy pay rate appears to have no significant relationship with the number of systems or discontinuities (H2a and H2c). Tests of the relationship between clinical pay rates and the count of systems are contrary to the hypothesis (H2b) as also for number of discontinuities (H2d). Finally, the results show that discontinuity in process automation is positively associated with the number of ADEs in the hospital (H3b).

Table 11 Effects of Automation Stage on Cost, Efficiency, and Quality

DV	PharmSalary	PharmRate	ClinSalary	ClinRate	ADEs
S1	0.0638	0.2691	0.0372	-0.0729	0.0132
S2a	0.0589	0.0007	-0.2710 **	-0.5843	-0.0638
S2b	0.0837	0.3408	-0.0069	0.1267	-0.0258
S3	0.1571 **	1.2026	-0.8254 ***	-5.6653 ***	-0.0490
cmi	0.1320	2.5777	0.0594	1.2705	1.0252 ***
y1999	-0.0530 **	0.3538	0.0368 *	0.1798	-0.0215
y2000	-0.0072	1.9003 ***	0.1116 ***	2.1187 ***	0.0080
y2001	0.0461 *	3.4577 ***	0.1875 ***	3.4675 ***	0.0543 ***
y2002	0.1243 ***	5.0281 ***	0.3503 ***	6.4768 ***	0.0597 ***
y2003	0.1958 ***	6.3670 ***	0.4811 ***	7.7424 ***	0.1199 ***
y2004	0.1225 ***	7.8876 ***	0.5496 ***	9.5655 ***	0.3053 ***
y2005	0.2710 ***	8.5106 ***	0.2729 ***	7.8711 ***	0.3946 ***
y2006	0.2999 ***	9.5498 ***	0.7999 ***	12.6726 ***	0.4382 ***
y2007	0.3231 ***	9.7441 ***	0.8113 ***	12.7690 ***	0.4688 ***
y2008	0.3087 ***	10.5516 ***	0.4592 ***	9.4871 ***	0.4660 ***
_cons	1.0168 ***	28.4351 ***	4.2172 ***	25.9881 ***	-3.7021 ***
R-Sq-w	0.1831	0.3998	0.1518	0.2876	0.5444
R-Sq-b	0.1492	0.1817	0.0061	0.1133	0.4703
R-Sq-o	0.1082	0.2599	0.0618	0.1900	0.4965

Note: 2856 observations, 341 hospitals. Using robust standard errors. *** sig. at .01, ** sig. at 0.05, * sig. at 0.10

The hypothesis tests related to the stages of the process again show support in relation to clinical costs (H4b). This test is done by linear combination of the coefficients of S2a and S2b. S2a should have a lower coefficient than S2b when the hypothesis is supported. This hypothesis is supported in the clinical cost calculations (p-value=0.002). However, there is no support for the hypotheses relating to pharmacy salary costs (H4a). Further, it is interesting to note that most of the savings related to process automation do not appear until the process is fully automated (i.e., Stage 3 is attained).

Table 12 Effects of Discontinuities on Efficiency

DV	Total Cost	Total Rate
mmc	-0.0397 *	-0.8328 ***
dis	0.0443 ***	0.4751 ***
cmi	0.0121	1.3019
y1999	0.0385	0.7649
y2000	0.1266 ***	2.8507 ***
y2001	0.1903 ***	4.2366 ***
y2002	0.3487 ***	7.2329 ***
y2003	0.4615 ***	8.6425 ***
y2004	0.4594 ***	10.5361 ***
y2005	0.4121 ***	8.8579 ***
y2006	0.6155 ***	13.2438 ***
y2007	0.6541 ***	13.7292 ***
y2008	0.4996 ***	10.9093 ***
_cons	3.2069 ***	26.6151 ***
R-Sq-w	0.1458	0.2983
R-Sq-b	0.0035	0.0729
R-Sq-o	0.0266	0.1791

Note: 2856 observations, 341 hospitals. Using robust standard errors. *** sig. at .01, ** sig. at 0.05, * sig. at 0.10

Table 13 Effects of Automation Stage on Efficiency

DV	Total Cost	Total Rate
S1	0.0721	-0.0526
S2a	-0.1045	-0.5094
S2b	0.0512	0.1542
S3	-0.2665 **	-5.0334 ***
cmi	0.0310	1.4309
y1999	0.0081	0.1900
y2000	0.0890 ***	2.1105 ***
y2001	0.1500 ***	3.4603 ***
y2002	0.3035 ***	6.3534 ***
y2003	0.4154 ***	7.6403 ***
y2004	0.4233 ***	9.4191 ***
y2005	0.3979 ***	7.9268 ***
y2006	0.6122 ***	12.4214 ***
y2007	0.6133 ***	12.5214 ***
y2008	0.4512 ***	9.5883 ***
_cons	3.1689 ***	26.0641 ***
R-Sq-w	0.1575	0.3101
R-Sq-b	0.0047	0.1230
R-Sq-o	0.0140	0.2040

Note: 2856 observations, 341 hospitals. Using robust standard errors. *** sig. at .01, ** sig. at 0.05, * sig. at 0.10

Finding different effects in the pharmacy and clinical environments suggests a follow-up analysis. What is the total cost to the hospital in terms of the pharmacy and clinical salaries and rates? Cost and rate variables associated with both these main players in the medication management process were created. The analysis was then rerun using the new variables (See Tables 12 and 13). The findings suggest that there is an overall 4% cost savings associated with processes with one less discontinuity. Further, there is a $0.47 decrease in rates. A stage analysis confirms that overall savings for average hospitals come only in Stage 3. Testing the linear combination of $s2a > s2b$ in regards to total cost shows support for the model (p-value=0.049).

4.5. Discussion

The hypothesis tests show support for key hypotheses of the model of process-based automation (see Table 14). This section discusses these findings from several different perspectives. First, the analysis and theory have implications related directly to the Meaningful Use rule of the American Recovery and Reinvestment Act. Second, the analysis also shows results outside of the hypotheses that are of interest to decision makers. Finally, the contributions of this work and implications for future research are discussed.

Table 14 Summary of Findings

Hypotheses	Findings
Extent of automation is negatively associated with labor costs	Supported in the clinical environment, contrary evidence in the pharmacy environment
Discontinuities in automation are positively related with labor costs	Supported in the clinical environment
Extent of automation is positively related with labor pay rates	Contrary evidence in the clinical environment
Discontinuities in automation are negatively associated with labor pay rates	Contrary evidence in the clinical environment
Extent of automation is negatively associated with adverse drug events	No findings
Discontinuities in automation are positively associated with adverse drug events	Supported
More cost benefits are associated with automating earlier stages of the process than with automating later stages.	Supported in the clinical environment

The basic premise of the theory developed and tested in this study is that information systems automate business processes and that automation and adoption strategies should take into account the business process context. Consistent with extant literature, the analysis provides evidence that the automation of activities in the process impact process cost. Further it is shown that discontinuity in process automation has cost and quality implications. In the clinical environment, each level of discontinuity in process automation was associated with an 8% higher salary costs. When combining the pharmacy and clinical costs, there is still a significant association between discontinuities and higher salary costs. It appears that although there is some shifting of costs, there is an overall cost reduction associated with corrections of discontinuities. Thus, discontinuities are likely to exacerbate demands on process workers and lead to higher personnel costs.

Automation at the beginning of the process is associated with lower costs than automation at the end of the process. Theoretically, this happens because controlling variance at the beginning of the process requires less effort in quality control and correction than does detection of the variance later in the process. Therefore, the findings clearly support the need to approach process automation in a systematic manner that targets specific up-front steps of the process first.

The results show a difference in the effects of automation and automation discontinuities in the pharmacy and clinical environments. Although automation lowered costs in the clinical environment, it was associated with higher costs in the pharmacy environment. Several reasons can be cited as potential sources of this finding. First, many hospitals employ clinical pharmacists. Clinical pharmacists work with doctors and nurses in the clinical environment to make pharmacy decisions. Anecdotal evidence suggests that hospitals hire more clinical pharmacists to work with the doctors in prescription decisions and to enter data into the computerized order system (Bhosle and Sansgiry 2004). Second, it appears the automation of the medication management systems is changing the role of the pharmacist. Because pharmacists have more immediate access to patient history and documentation, they have become more cognitively involved in the care process beyond simply dispensing drugs (Rough and Melroy 2009). Rough and Melroy (2009) further suggest that pharmacists need to take advantage of automation as their roles expand in order to accomplish all that is required of them. Whatever the reason, it appears that the expectation that automation would decrease the need for pharmacists must be tempered in light of the empirical evidence.

It is also possible that poor integration between systems contributes to increased costs in the Pharmacy. However, for lack of integration to have a material effect, rekeying data from the CPOE system to PIS and EMAR must contribute to an increased workload on the Pharmacy department (over and above what a paper-based system would have imposed). Increased workload may result from the need for reconciling prescription data in multiple systems, verifying drug utilization and interactions in multiple systems, and tracking and reconciling medication administration with prescriptions across the different implemented systems. In these cases, workload increases may likely be correlated with the number of systems implemented.

For appropriate interpretation of the results, some of the inherent limitations of this study should be considered. The data assume that after part of the process is automated there is no effect of un-automation or re-automation. If a system is not successful, it is conceivable that hospital management may decide to remove the system. More commonly, an old system may be replaced or upgraded. Both of these occurrences could have an effect on the outcome of the analysis. However, on average this is not likely the main effect seen in the data. Other effects unaccounted for include learning, IT usage, and the difference between early adopters and late adopters. Although the lags used in the analysis make it possible to account for some learning and organizational adjustment. Learning may be occurring when a hospital adopts an initial set of systems which allow it to more quickly adopt and gain benefits from subsequent systems. Usage data for the duration of the panel is unavailable.

Both the level of analysis and the scope of the data set are important in interpreting the outcomes of this study. The scope of the data makes it possible to generalize to the more technical hospitals in the California healthcare system. These hospitals may have unique issues which affect the outcome of the results. The OSHPD dataset has been used as the basis for many studies in the health-care literature (Brooke et al. 2009, McNair et al. 2009, McCue 2011). McCue (2011) studied financial and organizational issues. According to the author, a national survey by the Healthcare Financial Management Association provided some support that their findings using the OSHPD data could be generalized. Although it is impossible to generalize past the scope of any data set, findings based on this data set will provide a picture of what may be found in a national data set. Many U.S. hospitals are demographically represented in this sample. However, the sample is biased toward larger, non-government owned hospitals which treat more Medicaid patients.

Because the analysis is on the process level, the findings must be interpreted at that level. The analysis does not show the effect of adopting a specific system in a specific hospital. It simply reveals a correlation between the extent of automation and continuous automation in a process and the cost and quality outcomes of that process. Predicting the effect of each system requires system level analysis and data on the characteristics of each individual system.

As mentioned, current legislation is a motivator for hospitals to adopt and use medication management applications through the Meaningful Use (MU) program. There are three major implications of these findings in relation to MU. First, incentives for the adoption and use of these systems are scheduled for the next 10 years. The results of this study show that incentives for the implementation of these systems make sense. However, incentives should not be needed over the long-run. There is a significant correlation between the automation of the parts of the medication management process and lower salary costs in the clinical environment. Automation of one of the systems in the medication management process was associated with a 12.3% decrease in inpatient labor costs and a 2.9% increase in pharmacy labor costs. The second implication for meaningful use relates to continuity of automation within the process. The theory and analysis suggest that reimbursements should not focus on individual systems and functionality (as is currently the case). Substantial benefits are found in the continuous use of integrated systems. A gap in the automation of a process is associated with an 8.5% higher inpatient labor costs. Currently, incentives do not focus on the continuity of automation in the process. However, continuity of the process should be encouraged so that less reimbursement is needed over the long run. Finally, the staging model shows that automation in the forward part of the process is more beneficial than automation in the end of the process. Therefore incentives should also be weighted more in favor of earlier systems than for systems later in the care process. This is congruent with current MU objectives which focus more on CPOE than on EMAR.

The theory also suggests that investments in IT should take into account all intersecting business processes. In the simple context examined in this study, different effects in the pharmacy and inpatient environments are visible. Benefits may also be found in other intersecting processes through improvements in the quality of data available for inventory management and ordering as well as for diagnoses and treatment of patients. The whole process environment must be taken into account with emphasis on integration and the flow of the business process.

Although more testing is required for robust generalization, it is believed that this theory is generalizable to many business processes and information systems outside of healthcare. In summary, discontinuities in automation are associated with higher labor costs and lower quality. Automation at the beginning of the process is associated with a greater cost savings than automation at the end of the process. Significant portions of the effect appear to come after the whole process has been automated. Automation decisions need to take into account all business processes in which the system and its data will be involved. In assessing the value of information systems, both researchers and those making decisions to automate need to take into account the placement of the system in the process as well as the effects of the automation decision on the whole process.

4.6. Key findings and implications of chapter 4

This study develops a model of process-based automation using theory from business process, operations, and IT value literature. Hypotheses are developed in relation to the medication management process within hospitals. Data include 341 California hospitals. Hypotheses are tested using a fixed effects panel. Tests confirm hypotheses in relation to clinical labor costs as well as in relation to adverse drug events. The analysis does not provide supporting evidence in the hospital pharmacy environment. In a combined analysis of total costs, the analysis shows higher costs related to discontinuities further confirming several hypotheses.

The contributions of this study come from theory development, the development of a measure of contiguity of automation within the business process, and the use of a large sample of hospitals. Although previous work has alluded to the fact that the process is critical in automation, this is the first study detailing how systems fit into the automation environment of the process and why they should have different effects on cost and quality. The integration of the OSHPD data with the HIMSS Analytics database provides a novel perspective on healthcare IT. Finally the measure developed in this study for contiguity of systems within a process makes it possible to observe a phenomenon which has been hinted at but has been out of reach until now.

Chapter 4 has shown that discontinuities as defined by the business process indeed have a relationship with higher cost and lower quality. A basic assumption of the analysis of this chapter is that the systems included in the study are being used. Chapter 5 investigates this assumption. The amount of automation and configuration of systems may be affecting how the systems are used and in turn will affect the cost and quality associated with the process.

Chapter 5. The Role of System Use in Process-Based Automation Outcomes

5.1. Introduction

Information Systems usage is recognized in the literature as a key factor in the ability of an organization to realize value from IT investments (Devaraj and Kohli 2003, Davamanirajan et al. 2006). This is particularly the case when studying a complete set of systems for a business process. Data collected by the American Hospital Association (AHA) shows that many hospitals which have implemented a computerized physician ordering system (CPOE) do not use it for all their orders. The same survey also reveals that some hospitals have implemented CPOE and do not use their system at all. Much of the research on IT value assumes that systems are used (e.g. Menachemi et al. 2008, Angst et al. 2011). It is generally the case that systems are used to some extent when they are implemented. This study provides a much clearer view of how a full set of systems creates value by examining the role of use in the value creation process.

The literature provides little evidence of the effects of CPOE on process outcomes. Most studies focused on the adoption of CPOE (Culler et al. 2007, Menachemi et al. 2007 , Furukawa et al. 2008). Few studies have examined the effect of CPOE on cost and quality outcomes. Culler et al. (2007) studied the relationship between a set of applications which included CPOE. They found that availability of the IT applications was negatively associated with quality related to several medical condition specific measures. They also call for research to look at specific IT applications in specific clinical areas of the hospital. Very few studies include use of CPOE as part of the research model. Yu et al. (2009) found the

CPOE use had a positive impact on 5 medication related quality measures. Nevertheless, they did not include all process related systems. Though Yu et al.'s (2009) findings are helpful for decision makers, the omission of related systems can lead to biased results (Stoneman and Kwon 1994).

The objective of this study is to answer the question: Does system usage play an intermediate role between systems implementation and cost and quality outcomes? For systems usage to play an intermediate role, the analysis must demonstrate a relationship between IT characteristics and system use as well as a relationship between systems usage and cost and quality outcomes of the process. In order to answer this question, this study extends the model of process-based automation to include IT usage as a critical factor in value creation.

The model of process-based automation states that a business process is the defining factor in how systems create value and where interactions between systems will create additional value. IT factors in the model include the automation status of the whole process and automation gaps in the process. According to the model, value should generally be assessed at the process level. This study adapts the model to include automation usage as a mediator between automation and process outcomes.

The adaptations to the model are tested using cross-sectional data of over 2,000 United States acute care hospitals. Because the data show some evidence of endogeneity, the analysis is conducted using an ordered probit as a Heckman selection correction equation (Heckman 1979). The analysis shows that after accounting for automation of the medication management process, costs and quality are related to the percent of orders which go through the automated systems.

The following section explores additional relevant literature and develops the research model. Section three describes the data and the Heckman selection correction. Section four presents the analysis. Sections five and six discuss the results, implications, limitations and contributions of this work.

5.2. Literature and Research Model

This review will proceed as follows. First, a short motivation and overview of the model of process-based automation is provided. Then studies which consider the impacts of use on cost and quality will be discussed. The findings from the use literature will be used to extend the model of process-based automation. The model provides the hypotheses for the analysis. Finally, studies related directly to the adoption of CPOE are reviewed as a context for this study.

5.2.1. IT value and use

IT use is a key element of value creation associated with a set of process systems. In two different studies, Devaraj and Kohli (2000, 2003) suggest that lack of measurement of systems use is partially responsible for the divergent findings related to the value of IT. In one of the most recognized works relating IT and business processes in the healthcare context, Devaraj and Kohli (2000) conducted a panel study of eight hospitals over three years. They found that IT had an effect on revenue per admission and per patient day. They also found that business process reengineering decreased mortality and increased patient satisfaction. Together BPR and IT had a greater effect on revenue per admission and per patient day. Devaraj and Kohli (2003) later tested the effects of actual IT usage in the hospital setting. Their data spanned a number of hospitals all included in the same system. They found that the number of records accessed by the decision support system and the number of CPU cycles used were related to revenue and mortality measures at the hospital level. Their study suggested that the careful planning associated with implementation of decision support systems in the hospital allowed those systems to make almost immediate impacts on quality.

Davamanirajan et al. (2006) studied the letter of credit process in the banking industry. Their study is developed around two models, one of which is the process performance model. The process performance model predicts that performance and quality will be affected by both IT and non-IT characteristics of the process. They find that productivity (transactions per employee) increases as loan requests are increasingly made through associated online systems. Although there is great value in industry and organizational level studies published in the IS domain, they claim that focusing on the "loci of control and value" at the process level helps to inform daily decisions.

5.2.2. Process-Based Automation and IT Use

Just because a system is implemented does not mean that it will be used. According to the technology acceptance model, IT factors such as perceived usefulness and perceived ease of use can lead users to either use the system or find work-arounds (Davis 1985). For example, in hospitals, the nurses' ability to find alternative work processes is well documented (Tucker and Spear 2006). When users find work-arounds they are likely to use paper or verbal communication to complete the process. In many cases these exceptions to the process will need to be reconciled and entered into the system. In all cases, the quality controls of the process are circumvented. In the case of reconciliation and extra work required to circumvent the system, it is possible to predict increases in costs. In the case of circumvention of controls, quality may suffer.

Several factors can lead to finding work-arounds. The most direct application of the technology acceptance model says that when the systems in the process are difficult to use, users will find other ways to complete their work. Because vendors provide solutions which vary in usability, vendor choice may also be related to how well the system is used. Extension of this line of thought may suggest that the larger percent of the process, decision support, and related tasks that are automated, the more likely it is that users will continue to use the system. Lack of attention to the process and systems allows a variety of barriers to adoption to arise (i.e. Markus 1983). Disjoint systems may create complexity and compatibility issues in relation to the manual parts of the processes. Complexity and process compatibility are barriers to continued use (Karahanna et al. 1999). Users are likely to resist change and seek work-arounds which allow them to keep the status-quo.

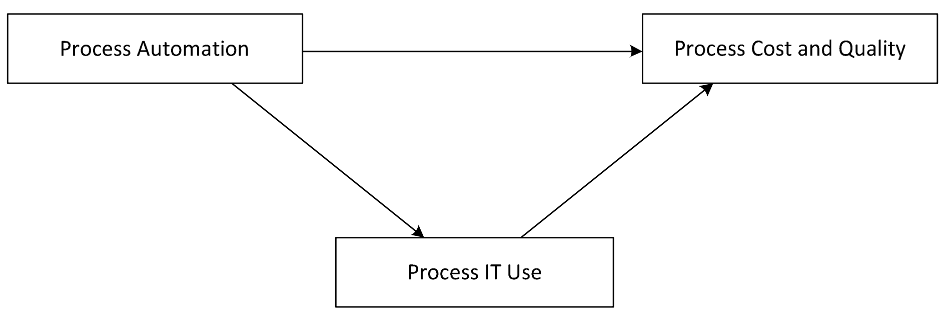
The structure of the organization can also impact the use of the system. For example, one of the largest challenges in successful implementation of CPOE is that physicians are not paid by the hospital and therefore cannot be forced to use the system. Although CPOE has been shown to improve patient quality, complete adoption appears to be limited to 4 to 10 percent of U.S. acute care hospitals

(Cutler et al. 2005, Furukawa et al. 2008). Providers are used to quickly writing on a piece of paper, signing it and handing it to the nurse or staff member. When using a system, they must remember log-on credentials. Physicians must also find their patient or the room in which the patient is located in order to create an order for them. They are also subject to many pop-ups which warn them or advise them about the prescriptions they are making. The system requires more work on the physicians' part and little immediate benefits. The technology acceptance model would then predict that physicians would not use the system. However, when physicians are employed by the hospital they may be given financial or other incentives to use the order entry system. Therefore organizational structure will also be related to the use of the system, particularly where the technology acceptance model would not predict acceptance.

To summarize, several factors lead to the relationship between IT and usage. First, perceived ease of use and perceived usefulness leads to higher usage (Davis 1985). Second, disjoint or discontinuous systems may be obstacles to usage such as those described in Karahanna et al. (1999). Further, systems which are implemented without consideration of the organizational context of process are less likely to be used by the end user (e.g. Markus 1983, Markus 2004). Because end users do not always use the system, the effects of automation on process outcomes should be mediated by use. Using process systems should be associated with higher quality and lower costs. This is evidenced in the healthcare domain (Yu et al. 2009). I now posit that as users work around the system and its controls, more manual work is required. Further, without system controls, more out-of-bounds variance can be expected. The model of process-based automation also includes a direct link to process cost and quality.

Nevertheless, not all of the effects of implementation of process systems on process outcomes are mediated by use. Even though variation may not be as well controlled when the system is not used transactions are often recorded in the system post-hoc. This provides a record and accountability. Further, implementation of a system usually requires that stakeholders examine their processes in order to find or build a system that will fit the needs of the organization. Effects of process systems on process outcomes are thus expected even when use is minimal (see Figure 7).

Figure 7   Research Model



5.2.3. Related Empirical Research

The empirical context for this study is the adoption and use of CPOE in the medication management process within acute care hospitals. The purpose of this section is to provide a relevant sample of studies related to CPOE to provide a foundation for this research. I note however that there is a large and growing body of literature on the adoption of CPOE. Though many studies have focused on the adoption of CPOE (Cutler et al. 2005, Culler et al. 2007, Menachemi et al. 2007, Furukawa et al. 2008, Menachemi et al. 2008, Yu et al. 2009) few have examined actual usage across a large sample of hospitals. More importantly, most studies did not approach the analysis from a process perspective. Including actual use of the system will provide much better insight into the effect of automation on the business process.

One body of literature has observed that the adoption of CPOE and other healthcare information systems are related to hospital characteristics. Cutler et al. (2005) studied this relationship using data based off of a Leapfrog Group survey of 937 hospitals in 2002 and 2003. They found that government hospitals were more likely to adopt CPOE than other types of hospitals. Furukawa et al. (2008) made a similar observation using the HIMSS Analytics 2006 database. Government hospitals were more likely to adopt CPOE than investor-owned hospitals. However, they found that not-for-profit hospitals were most likely to adopt CPOE.

Other work has observed that the availability of these systems has an impact on quality. Culler et al. (2007) studied the relationship between a set of applications which included CPOE and 15 patient safety indicators provided by the Agency for Healthcare Research and Quality (AHRQ). They found that availability of the IT applications was negatively associated with several medical condition specific measures. They call for research to look at specific IT applications in specific clinical areas of the hospital.

Jha et al. (2009) reported the results of a survey conducted in 2007 in conjunction with the American Hospital Association (AHA) in which they asked about both adoption and use of hospital information systems. This survey is available through the AHA and is the basis of adoption and use variables in the present work. Jha et al. (2009) found that only 1.5% of the surveyed hospitals had a comprehensive electronic health record (EHR). Only about 10% of hospitals had implemented a basic CPOE system with other basic EHR capabilities.

The literature does not cover the effects of CPOE use on cost and quality directly. Most empirical studies have studied the adoption characteristics of hospitals, the relationship between the availability of CPOE and patient outcomes as well as the hospital characteristics related to the use of health information technology. The basic assumption of most of this body of literature is that these systems are being used. The 2007 AHA data set used in this study makes it possible to test that assumption.

5.3. Methods

This section will describe data sources for the adoption, usage, hospital demographic, and financial data used in this study. Descriptive statistics are provided. Section 3.2 will discuss the analytic approach adopted in this research.

5.3.1. Data

In 2007, the American Hospital Association (AHA) added an IT supplement to their annual survey of member hospitals. That survey includes questions on the percent of prescriptions that were ordered through the automated system. Merging the two data sets is problematic for several reasons. The most challenging is that the surveys are generally completed by different individuals or departments at the hospital. Therefore, the IT variables in this data set are limited to those from the extended AHA survey. The annual survey of the AHA also provides demographic information related to the hospital. Use of the annual survey of the HIMSS Foundation on healthcare IT adoption was considered for usage data. The HIMSS data provides some limited estimates of CPOE use. Nevertheless, this data is not reliable and has many null values before 2008. The data from HIMSS Analytics does provide vendor information for the sample used in this study.

Financial measures are calculated from data provided by the Center for Medicare and Medicaid Services (CMS). The data from CMS provide pharmacy salary costs and clinical salary costs. Quality data related to evidence-based medicine (EBM) is provided through a joint venture of CMS and the Hospital Quality Alliance (HQA). Measures of EBM related to medication management are separated into four categories: acute myocardial infarction (AMI), heart failure (HF), pneumonia (PNE), and surgical and impatient procedures (SIP). Combined this dataset offers a sample of 2275 U.S. hospitals. However, where data are missing or where observations of quality are not high enough to reliably calculate a percentage of quality, the sample size is slightly smaller.

Several variables are specific to the healthcare industry (see Table 15). The sophistication index is a weighted measure of the procedures available at the hospital. Procedures that are less common are given a heavier weighting. Accreditation by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) is considered an important control in the literature.

Hospitals which are associated with medical schools or are a member of the Council of Teaching Hospitals (COTH) may have different cost structures and technical capabilities than other hospitals. Because this data is nationally representative, region dummies are used as follows: the northeast region (CT, MA, ME, NH, RI, VT, NJ, NY, and PA), the southeast region (DC, DE, FL, GA, MD, NC, SC, VA, WV), the south-central region (AL, KY, MS, TN, AR, LA, OK, TX), the north-central region (IL, IN, MI, OH, WI, IA, KS, MN, MO, ND, NE, SD), the mountain region (AZ, CO, ID, MT, NM, NV, UT, WY), and the pacific region (AK, CA, HI, OR, WA).

Several variables require adjustment for accurate estimation. Because of the variation in size difference in the hospitals, it is necessary to divide the yearly salaries by the number of patient days for each hospital. Patient days refers to the sum of the length of stay of all the patients in the hospital for the given time period. Cost variables as well as bed size are highly skewed to the right and are corrected using a logarithmic transformation for analysis.

Table 15 Summary Statistics

Variable	Mean(S.D.)	Observations
Pharmacy salary per patient day	$33($27)	2275
Clinical salary per patient day	$279($117)	2275
Bed size	216(213)	2275
% Payer from Medicare	47%(13%)	2275
% Payer from Medicaid	17%(10%)	2275
Sophistication index	4.14(2.05)	2275
Government	20.48%	2275
For-profit	12.66%	2275
Not-for profit	55.30%	2275
Rural	16.18%	2275
Micro	19.08%	2275
Metro	64.75%	2275
JCAHO	81.45%	2275
COTH member	9.19%	2275
Associated with a medical school	30.11%	2275
Northeast region	16%	2275
Southeast region	17.19%	2275
South-center region	20.75%	2275
North-center region	27.25%	2275
Mountain region	5.89%	2275
Pacific region	10.24%	2275
AMI related EBM Success	93%(10%)	2029
HF related EBM Success	89%(10%)	2026
PNE related EBM Success	87%(9%)	2254
SIP related EBM Success	84%(11%)	2012

There are two types of IT variables used in this study. The first measures the specific functionality which has been automated within the medication management process. The scope of the AHA data on information systems limits the application set to CPOE, clinical documentation (CD), and electronic medication administration records (EMAR). Each question related to these three systems is measured on six levels: fully implemented across all units, fully implemented in at least one unit, beginning to implement in at least one unit, have resources to implement in the next year, do not have resources but considering implementing, and not in place and not considering implementing. This study is concerned mainly with the process and immediate process outcomes. Therefore the data are recalculated into three groups: not implemented, implemented in some units of the hospital, implemented in the whole hospital.

The second type of IT variable is use of the CPOE system. The AHA survey measured the percent of orders processed through CPOE. The survey records responses in the following categories: 0%, 1-25%, 26-50%, 51-90%, and 91-100%. Although this categorization is not optimal for analysis and interpretation, it categorizes the hospitals by non-users, partial users (low, medium and high), and full users. The analysis will retain the original variable.

Table 16 CPOE Usage

Use	Hospitals	Percent
0%	1,315	58.65
1-25%	310	13.83
26-50%	103	4.59
51-90%	154	6.87
91-100%	360	16.06

5.3.2. Heckman Selection Correction with an Ordered Probit

Several approaches were taken to account for usage as a mediating variable including two-stage least squares and the Sobel and Goodman tests (Sobel 1982). However, selection appears to be endogenous because hospitals which will gain the most from using the system are the hospitals which use it. Therefore, a selection bias correction model is chosen.

Because use is determined in part by the benefits that can be derived from use estimation of equation 1 yields inconsistent results.

$$y = c + \beta x + \delta w + \varepsilon \qquad (1)$$

Where:

$y =$ quality or cost

$x =$ exogenous variables such as controls and IT factors

$w =$ the endogenous discrete ordered variable use

The following steps, described in Chiburis and Lokshin (2007), are required to correct for endogeneity. The first step is to estimate an ordered probit as follows:

$$w = c + \gamma z + \pi x + \varepsilon \qquad (2)$$

Where z is a selection restriction variable. The selection restriction variable works exactly as an instrumental variable. Then using estimates from the selection equation (3), the inverse Mills ratio ($\hat{\lambda}$) is calculated (Heckman 1979). Finally, using $\hat{\lambda}$, β can be consistently estimated by estimating an equation for each discrete value contained in w.

After estimating β it is possible to estimate the unbiased y. After completing the selection correction, the unbiased outcome variable will be predicted. That prediction is then examined across different levels of usage in order to determine the relationship between usage and the outcome variable.

The following section describes the results of the Heckman correction using an ordered probit model.

5.4. Analysis

5.4.1. Factor Analysis

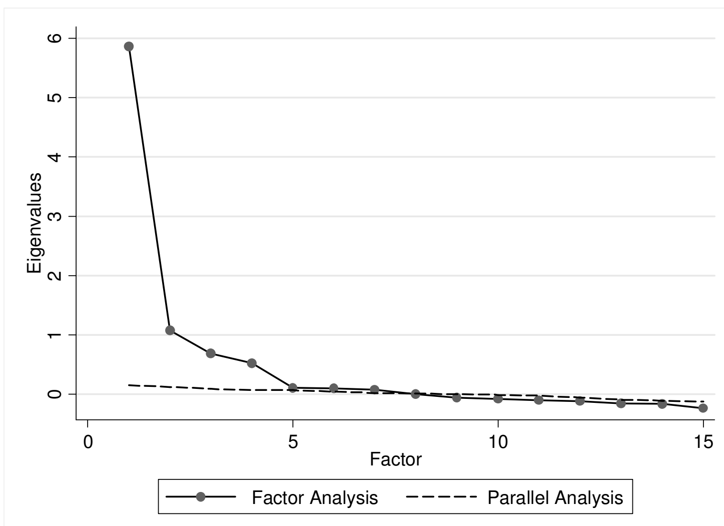
The EHR supplement to the 2007 AHA survey includes many items related to healthcare IT within the hospital. Fifteen of these were selected as functionality of systems which participate in the medication management process. These 15 instruments are shown in Table 17.

Table 17 Survey Instruments from the EHR Supplement to the 2007 Annual Survey of the AHA

1.	**Does your hospital have a computerized system for:** (Fully implemented means it has completely replaced paper record for the function.)						
		(1) Fully Implemented Across All Units	(2) Fully Implemented in At Least One Unit	(3) Beginning to Implement in At Least One Unit	(4) Have Resources to Implement in the Next Year	(5) Do not have Resources but Considering Implementing	(6) Not in Place and not Considering Implementing
Electronic Clinical Documentation							
a.	Patient Demographics	□	□	□	□	□	□
b.	Physician Notes	□	□	□	□	□	□
c.	Nursing Assessments	□	□	□	□	□	□
d.	Problem Lists	□	□	□	□	□	□
e.	Medication Lists	□	□	□	□	□	□
g.	Advanced Directives	□	□	□	□	□	□
Computerized Provider Order Entry (Provider (e.g., MD, APN, NP) directly enters own orders)							
c.	Medications	□	□	□	□	□	□
Decision Support							
a.	Clinical Guidelines (e.g., Beta blockers post-MI, ASA in CAD)	□	□	□	□	□	□
b.	Clinical Reminders (e.g., pneumovax)	□	□	□	□	□	□
c.	Drug Allergy Alerts	□	□	□	□	□	□
d.	Drug-Drug Interaction Alerts	□	□	□	□	□	□
e.	Drug-Lab Interaction Alerts	□	□	□	□	□	□
f.	Drug Dosing Support (e.g., renal dose guidance)	□	□	□	□	□	□
Bar Coding							
c.	Pharmaceutical administration	□	□	□	□	□	□
e.	Patient ID	□	□	□	□	□	□
5.	**Please provide your best estimate for …**						
			0%	1-25%	26-50%	51-90%	51-100%
a.	The percentage of inpatients at your hospital for whom medication orders are written electronically?		□	□	□	□	□

Factor analysis was used to reduce the survey items to general IT factors. Exploratory factor analysis was run using all 15 items. The number of factors to retain was decided by parallel analysis. The theory behind parallel analysis states that non-trivial factors will have eigenvalues greater than factors derived from a similar random data set (Hayton et al. 2004). It has been shown that parallel analysis yields more accurate decisions in retaining factors than the traditional heuristic that eigenvalues must be greater than 1 (Silverstein 1987). The scree plot depicted in Figure 8 shows four factors should be considered non-trivial. Traditional scree plot analysis would provide a similar conclusion as there seems to be drop after the fourth factor (Cattell 1966).

Figure 8 EFA with Parallel Analysis



Several different theoretical divisions of the survey items were developed and tested using confirmatory factor analysis. Each of the three approaches had strong similarities to the loadings provided by the exploratory factor analysis. The first set of factors was designed by functional purpose. Some functions were used for entry, some for decision support and others for controlling outputs. The second set was by process player which includes the physicians, pharmacists, and nurses. The third and strongest factor analysis was provided by system type (CPOE, CD, and ADM) and by dividing the CPOE category into medication entry and decision support factors. The final set of factors provided acceptable RMSEA and RMSA. Further, the TLI and CFI were both reasonably high (see Table 18). These four factors became the basis of the independent IT variable used in the Heckman selection corrected regressions.

Table 18 CFA Factor Loadings and Fit Statistics

Factor	Loading
CPOE Inputs (CPOE_OE)	
medication orders	1.0000
medication guidelines	1.8728
medication reminders	2.2448
CPOE Decision Support (CPOE_DS)	
drug-allergy interactions	1.0000
drug-drug interactions	1.0092
drug-lab interactions	0.8448
drug dosage support	0.7563
Clinical Documentation (CD)	
patient demographics	1.0000
physician notes	1.0691
problem lists	2.0282
medication lists	2.0316
advanced directives	1.6824
nurse assessments	2.1938
Electronic Medical Administration Record (EMAR)	
medication barcoding	1.0000
patient barcoding	1.1875

Fit Statistics	
RMSEA	0.0796
RMSA	0.0460
TLI	0.9818
CFI	0.9222

5.4.2. Selection Restrictions and Selection Equation

Before running the Heckman correction, it is necessary to evaluate the assumptions and need for the model. The main issue requiring the use of the Heckman correction is that a selection bias is occurring. To test the existence of this bias and to run the model assumes that sufficient instrumental variables exist. The adapted model of process-based automation proposes that organizational structure and IT vendors may serve as suitable selection restrictions. Vendor dummy variables were created for the top three vendors which account for 50% of the market. Another binary variable accounts for the other vendors in the sample. The number of full-time equivalent (FTE) medical doctors employed by the hospital is used as an organizational structure variable. For use in this analysis, the variable is divided by the number of patient days.

These variables were evaluated in several ways. First, it is noted that the selection variables were all more highly correlated with usage than with the outcome variable. Further, an augmented regression was used to test the quality of the instrumental variables (Davidson and MacKinnon 1993). The augmented regression showed that the OLS results were not consistent. The best instrumental variable appeared to be adjusted FTE medical doctors. The vendor variables were weaker instruments.

The analysis was estimated with both maximum likelihood and two-step estimators. The maximum likelihood estimation provides variance estimates for rho and therefore allows a Wald test of independent equations. If this statistic is insignificant, the OLS would provide an unbiased result. In this case the Wald test was significant which confirms the augmented regression results. It is necessary to correct the regression using the selection equation and subsequent inverse Mills ratio. The two step results were reported because they are more robust particularly against non-normal shocks. Although the maximum likelihood estimator is more efficient, for most practical applications, the two-step estimator should be used (Chiburis and Lokshin 2007).

Table 19 presents the selection equation used in the selection bias corrected regressions. The instrumental variables are suitable for use in all the cost and quality equations, therefore the selection equation will be identical in all the analyses. The analysis shows that the number of medical doctors does have an impact on use. Hospitals that have more employed medical doctors have higher use of their CPOE systems. Variety in vendor solutions does seem to matter. Using linear combinations it can be shown that CPOE vendor 3 (vendor_3) has the highest use responses. There is minimal difference in use by geographic region after controlling for other factors.

Table 19 Selection Equation – DV = % orders entered electronically

	Selection Eq. DV=Use	
Employed physicians	0.164 (0.072)	**
Vendor_1	0.228 (0.110)	**
Vendor_2	0.229 (0.132)	*
Vendor_3	0.889 (0.144)	***
Vendor_other	0.421 (0.084)	***
CPOE_OrderEntry	1.073 (0.132)	***
CPOE_Decision Support	-0.010 (0.050)	
CD	0.726 (0.156)	***
EMAR	-0.002 (0.068)	
Ln(bedsize)	-0.020 (0.043)	
Medicare payer mix	-0.007 (0.003)	**
Medicaid payer mix	0.001 (0.003)	
Sophistication index	0.008 (0.017)	
Government run	0.024 (0.075)	
For-profit-run	-0.091 (0.091)	
Member of a system	0.197 (0.059)	***
JCAHO Accreditation	-0.299 (0.088)	***
Rural location	-0.083 (0.094)	
COTH member	0.314 (0.106)	***
Medical school affiliation	0.074 (0.069)	
Region_se	-0.168 (0.092)	*
Region_sc	0.019 (0.091)	
Region_nc	-0.078 (0.081)	
Region_mt	-0.033 (0.129)	
Region_pa	0.003 (0.107)	

Note: Standard errors are in parentheses.
*** sig. at .01, ** sig. at 0.05, * sig. at 0.10.

The analysis provides some support that the systems in the end-to-end process matter. The IT factors from the CFA also have an impact on electronic order entry. First, note the obvious fact that hospitals which have implemented the order entry functions of CPOE (CPOE_OE) are more likely to have their orders entered electronically than hospitals which have not implemented the input functions of

CPOE. More interestingly the model of process-based automation suggests that the more of the process is automated, the more likely users will use the process. As more of the clinical documentation is automated, the hospital is more likely to use the CPOE system.

5.4.3. Regressions of Use on Performance

Tables 20 and 21 present the results of the Heckman correction regression on adjusted pharmacy and adjusted clinical salaries. There is little effect of IT on performance after dividing the sample by usage. There is also substantial regional variation in clinical salaries per patient day.

Table 20 Regression on ln(Pharmacy Salaries per Patient Day) using Heckman Selection Correction Selection Equation

Usage	0%	1-25%	26-50%	51-90%	91-100%
_lambda	0.044 (0.452)	-0.620 (0.441)	1.200 (0.600) **	-0.904 (0.581)	0.401 (0.422)
CPOE Order Entry	-0.375 (0.380)	-1.267 (0.712) *	1.436 (1.050)	-0.624 (0.802)	0.615 (0.565)
CPOE Decision Support	0.049 (0.075)	0.124 (0.183)	0.520 (0.285) *	0.104 (0.267)	0.122 (0.169)
CD	0.243 (0.114) **	-0.325 (0.250)	-0.184 (0.400)	0.397 (0.323)	-0.003 (0.178)
EMAR	0.092 (0.295)	0.233 (0.662)	0.862 (1.083)	-1.477 (0.880) *	-0.339 (0.514)
Ln(bedsize)	0.245 (0.067) ***	-0.005 (0.156)	0.315 (0.245)	0.840 (0.211) ***	0.192 (0.132)
Medicare payer mix	-0.005 (0.005)	0.018 (0.009) *	0.009 (0.015)	0.019 (0.011) *	-0.002 (0.010)
Medicaid payer mix	-0.002 (0.005)	-0.003 (0.011)	0.017 (0.016)	0.000 (0.013)	0.008 (0.008)
Sophistication index	0.027 (0.029)	0.051 (0.070)	0.019 (0.103)	-0.111 (0.076)	0.047 (0.047)
Government run	-0.187 (0.113) *	-0.258 (0.268)	0.354 (0.491)	-0.148 (0.376)	-0.365 (0.229)
For-profit-run	-0.240 (0.144) *	0.098 (0.342)	0.942 (0.579)	0.204 (0.432)	-0.389 (0.293)
Member of a system	0.241 (0.106) **	-0.205 (0.223)	-0.257 (0.331)	-0.640 (0.306) **	-0.284 (0.185)
JCAHO Accreditation	0.290 (0.148) **	1.454 (0.343) ***	1.006 (0.526) *	0.311 (0.462)	0.040 (0.302)
Rural location	-0.250 (0.136) *	-0.297 (0.408)	-0.954 (0.505) *	-0.094 (0.416)	-1.155 (0.337) ***
COTH member	-0.146 (0.248)	0.594 (0.388)	0.283 (0.577)	0.439 (0.519)	0.184 (0.284)
Medical school affiliation	-0.049 (0.118)	0.082 (0.234)	-0.296 (0.325)	-0.745 (0.352) **	0.069 (0.203)
Region_se	-0.593 (0.159) ***	-0.625 (0.341) *	-0.543 (0.529)	0.594 (0.439)	-0.358 (0.281)
Region_sc	-0.896 (0.149) ***	-0.832 (0.309) ***	-0.859 (0.506) *	0.297 (0.407)	-0.991 (0.275) ***
Region_nc	-0.939 (0.139) ***	-0.550 (0.275) **	-0.428 (0.411)	0.151 (0.365)	-0.603 (0.234) ***
Region_mt	-0.326 (0.213)	0.519 (0.492)	-0.259 (0.763)	0.296 (0.541)	-0.015 (0.368)
Region_pa	0.120 (0.173)	-0.028 (0.373)	0.645 (0.534)	0.943 (0.508) *	0.704 (0.327) **
_cons	2.109 (0.615) ***	1.276 (0.960)	-0.852 (1.413)	-0.678 (1.254)	1.560 (1.074)

Note: Standard errors are in parentheses. *** sig. at .01, ** sig. at 0.05, * sig. at 0.10

Table 21 Regression on ln(Clinical Salaries per Patient Day) using Heckman Selection Correction Selection Equation

Usage	0%	1-25%	26-50%	51-90%	91-100%
_lambda	-0.141 (0.102)	-0.027 (0.067)	0.032 (0.146)	-0.141 (0.279)	-0.243 (0.086) ***
CPOE Order Entry	-0.162 (0.086) *	0.052 (0.109)	-0.009 (0.258)	0.211 (0.384)	-0.120 (0.112)
CPOE Decision Support	-0.006 (0.017)	-0.023 (0.028)	0.067 (0.070)	-0.201 (0.129)	-0.015 (0.033)
CD	0.013 (0.026)	0.041 (0.038)	-0.107 (0.099)	0.161 (0.156)	0.012 (0.036)
EMAR	-0.010 (0.067)	-0.018 (0.101)	0.495 (0.267) *	-0.177 (0.424)	-0.115 (0.102)
Ln(bedsize)	-0.107 (0.015) ***	-0.116 (0.024) ***	-0.042 (0.060)	-0.089 (0.102)	-0.121 (0.026) ***
Medicare payer mix	-0.001 (0.001)	-0.003 (0.001) *	-0.006 (0.004)	0.007 (0.005)	-0.005 (0.002) ***
Medicaid payer mix	-0.006 (0.001) ***	-0.008 (0.002) ***	-0.005 (0.004)	-0.003 (0.006)	-0.007 (0.002) ***
Sophistication index	0.027 (0.007) ***	0.020 (0.011) *	0.009 (0.025)	-0.012 (0.037)	-0.001 (0.009)
Government run	0.031 (0.026)	0.033 (0.041)	0.032 (0.122)	0.182 (0.182)	0.045 (0.045)
For-profit-run	-0.112 (0.033) ***	-0.123 (0.053) **	-0.101 (0.144)	0.106 (0.208)	-0.174 (0.057) ***
Member of a system	-0.051 (0.024) **	-0.021 (0.034)	-0.041 (0.081)	-0.084 (0.147)	-0.039 (0.037)
JCAHO Accreditation	-0.050 (0.034)	0.092 (0.053) *	-0.140 (0.129)	-0.047 (0.223)	-0.090 (0.059)
Rural location	0.014 (0.031)	0.024 (0.063)	0.130 (0.124)	0.057 (0.200)	-0.043 (0.065)
COTH member	-0.093 (0.056) *	0.068 (0.059)	-0.041 (0.141)	-0.159 (0.249)	0.060 (0.057)
Medical school affiliation	0.025 (0.027)	-0.011 (0.036)	0.070 (0.079)	0.258 (0.170)	-0.002 (0.040)
Region_se	-0.051 (0.036)	-0.152 (0.052) ***	-0.040 (0.130)	0.327 (0.211)	0.026 (0.056)
Region_sc	-0.151 (0.034) ***	-0.326 (0.047) ***	-0.162 (0.125)	0.032 (0.196)	-0.209 (0.054) ***
Region_nc	0.113 (0.032) ***	-0.044 (0.042)	0.085 (0.100)	0.487 (0.175) ***	0.017 (0.047)
Region_mt	0.065 (0.049)	-0.106 (0.076)	0.132 (0.188)	0.457 (0.259) *	0.054 (0.073)
Region_pa	0.378 (0.040) ***	0.101 (0.057) *	0.392 (0.131) ***	0.916 (0.244) ***	0.294 (0.064) ***
_cons	6.063 (0.140) ***	6.349 (0.147) ***	6.111 (0.346) ***	5.488 (0.602) ***	7.063 (0.212) ***

Note: Standard errors are in parentheses. *** sig. at .01, ** sig. at 0.05, * sig. at 0.10

The Heckman corrected regression shows that within the different use types, there is not much effect of the IT variables on pharmacy salary. The EMAR factor which includes barcoding of patients and drugs is associated with higher pharmacy salaries.

Selection correction enables estimation of the unbiased adjusted pharmacy salaries for each of the use categories (see Figure 9). The first three groups are not significantly different from one another. However, the last two groups show a significant rise and then fall in pharmacy salaries per patient day. This analysis largely confirms the model in that IT factors are affecting use and that use is directly related to pharmacy salaries.

Figure 9 Predicted Pharmacy Salaries at Different Levels of CPOE Use

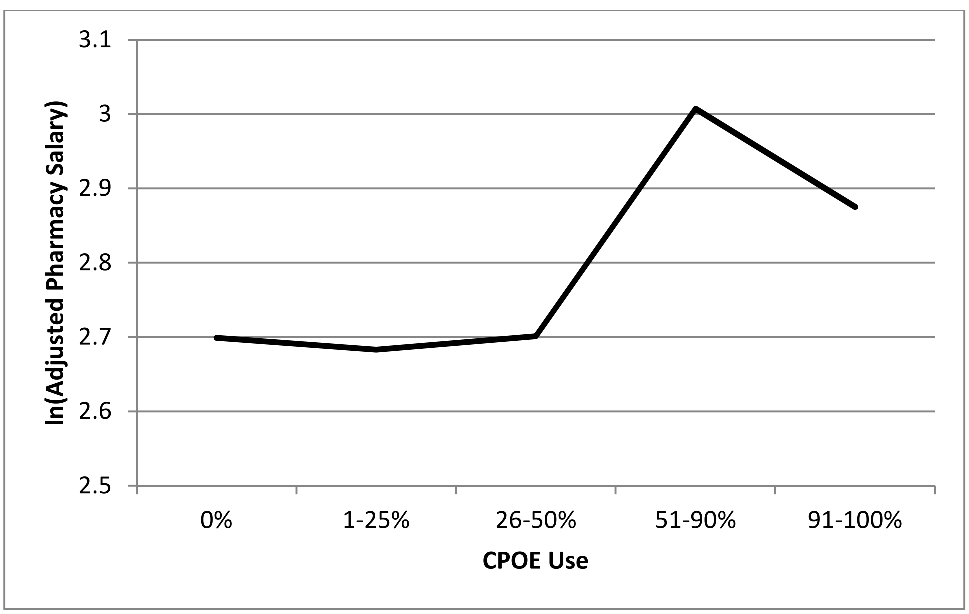
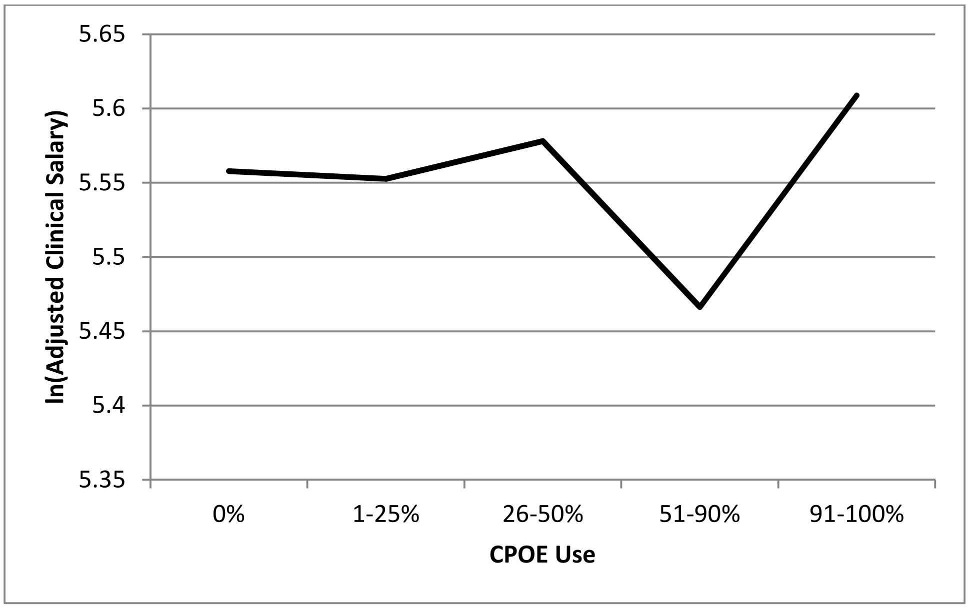


Figure 10 shows the predicted clinical salaries per patient day after correcting for selection bias. Again, the first three groups are not significantly different.

However, there is a significant drop in and then rise in clinical salary costs per patient day in the fourth and fifth groups. This confirms that different levels of systems use are associated with different labor costs.

Figure 10 Predicted Clinical Salaries at Different Levels of CPOE Use



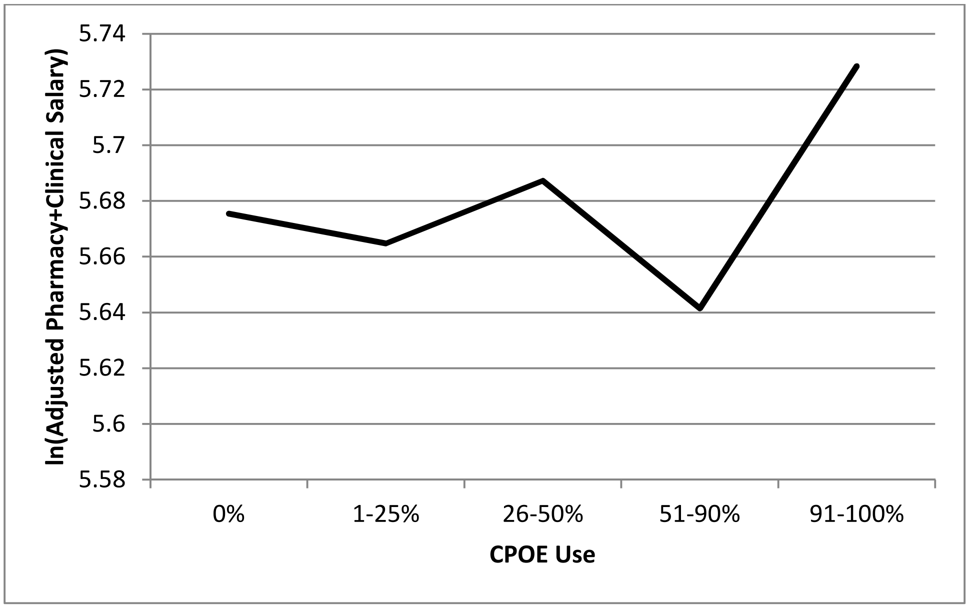
In order to look at overall labor costs of the process, total pharmacy and clinical salaries per patient day were used. The Heckman corrected regressions show similar results with little to no effect of IT on the process outcomes without use (see Table 22). Figure 11 shows a pattern which is more similar to clinical salaries than to pharmacy salaries. This is not unexpected as clinical salary costs per patient day are much higher than pharmacy salary costs per patient day, and therefore have a dominant effect on total costs.

Table 22 Regression on ln(Pharmacy and Clinical Salaries per Patient Day) using Heckman Selection Correction Selection Equation

Usage					
_lambda	-0.088 (0.092)	-0.052 (0.066)	0.057 (0.133)	-0.159 (0.161)	-0.209 (0.082) **
CPOE Order Entry	-0.140 (0.077) *	0.000 (0.107)	0.041 (0.234)	-0.070 (0.221)	-0.090 (0.108)
CPOE Decision Support	-0.006 (0.015)	-0.019 (0.028)	0.087 (0.064)	-0.110 (0.074)	-0.002 (0.031)
CD	0.020 (0.023)	0.025 (0.038)	-0.090 (0.090)	0.133 (0.089)	0.008 (0.034)
EMAR	0.010 (0.060)	-0.015 (0.100)	0.426 (0.243) *	-0.033 (0.244)	-0.104 (0.098)
Ln(bedsize)	-0.091 (0.014) ***	-0.118 (0.023) ***	-0.022 (0.055)	-0.064 (0.058)	-0.102 (0.025) ***
Medicare payer mix	-0.002 (0.001)	-0.002 (0.001)	-0.005 (0.003)	0.005 (0.003) *	-0.005 (0.002) ***
Medicaid payer mix	-0.006 (0.001) ***	-0.008 (0.002) ***	-0.005 (0.004)	-0.004 (0.004)	-0.006 (0.002) ***
Sophistication index	0.019 (0.006) ***	0.022 (0.011) **	0.006 (0.023)	-0.013 (0.021)	0.000 (0.009)
Government run	0.025 (0.023)	0.034 (0.040)	0.061 (0.111)	0.106 (0.104)	0.030 (0.043)
For-profit-run	-0.129 (0.029) ***	-0.121 (0.052) **	-0.027 (0.130)	0.044 (0.119)	-0.185 (0.055) ***
Member of a system	-0.025 (0.022)	-0.028 (0.034)	-0.072 (0.074)	-0.083 (0.085)	-0.044 (0.035)
JCAHO Accreditation	-0.034 (0.030)	0.158 (0.052) ***	-0.062 (0.118)	-0.028 (0.128)	-0.094 (0.057) *
Rural location	0.001 (0.028)	0.013 (0.062)	0.089 (0.113)	0.046 (0.115)	-0.089 (0.063)
COTH member	-0.019 (0.050)	0.102 (0.058) *	-0.002 (0.128)	-0.029 (0.143)	0.075 (0.055)
Medical school affiliation	0.027 (0.024)	-0.001 (0.035)	0.049 (0.072)	0.154 (0.097)	0.002 (0.039)
Region_se	-0.080 (0.033) **	-0.158 (0.051) ***	-0.062 (0.118)	0.201 (0.121) *	0.007 (0.054)
Region_sc	-0.186 (0.030) ***	-0.323 (0.047) ***	-0.197 (0.113) *	-0.043 (0.112)	-0.228 (0.052) ***
Region_nc	0.064 (0.028) **	-0.039 (0.042)	0.069 (0.091)	0.339 (0.101) ***	0.015 (0.045)
Region_mt	0.051 (0.044)	-0.047 (0.074)	0.143 (0.171)	0.336 (0.149) **	0.078 (0.070)
Region_pa	0.349 (0.035) ***	0.110 (0.056) *	0.405 (0.119) ***	0.738 (0.140) ***	0.319 (0.062) ***
_cons	6.198 (0.125) ***	6.380 (0.145) ***	6.039 (0.315) ***	5.798 (0.346) ***	7.009 (0.204) ***

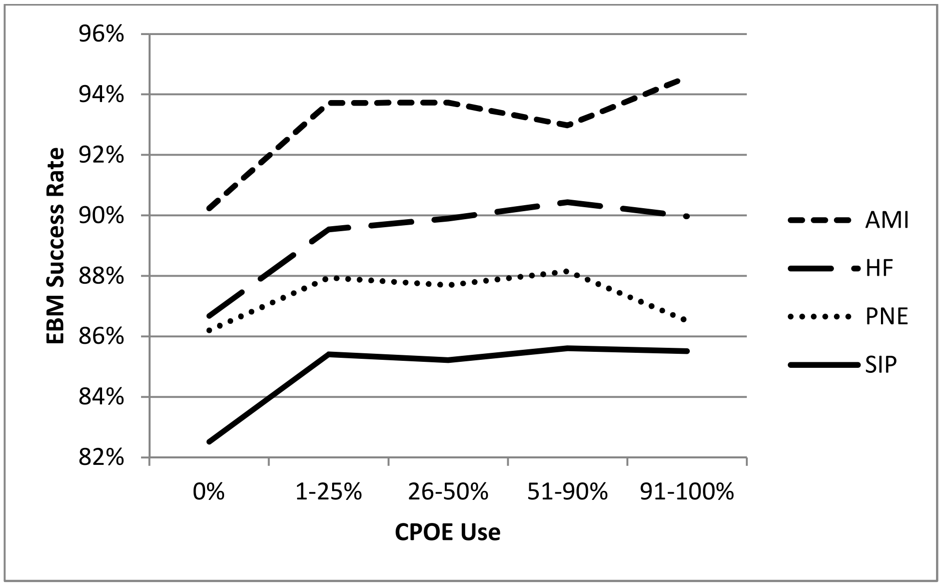
Note: Standard errors are in parentheses. *** sig. at .01, ** sig. at 0.05, * sig. at 0.10

Figure 11 Predicted Pharmacy and Clinical Salaries at Different Levels of CPOE Use



Finally, the analysis was also run on the four different EBM quality measures. The output of the regressions is omitted with the note that within groups of use, there is little to no effect of automation on the quality outcomes. The selection bias-corrected quality variables were calculated and are displayed in Figure 12. A significant improvement in quality is noted between no use and some use. Categories representing 1% to 90% use are not significantly different. Quality measures related to acute-myocardial infarction increase significantly for the final use group. In contrast, pneumonia related quality measures decrease in the final group of use.

Figure 12 Predicted Quality at Different Levels of CPOE Use



Overall, the analysis supports the model. Usage has a relationship with automation, IT vendors, and organizational structure. Use has a definite relationship with both cost variables and with quality. Weak evidence was provided by the analysis to show that IT has a direct impact on cost and quality. The effect comes largely through use of the system.

5.5. Discussion

Several observations can be made from the analysis in support of the model of process-based automation. The first general observation in the analysis is that labor costs rise with the implementation of IT. This is particularly the case when comparing no use of electronic medication entry to full use of electronic medication entry. This may be due to the fact that computer literate labor is more expensive than labor that is not computer literate (Bresnahan et al. 2002). It appears that in this environment any savings from reduction in labor due to automation is offset by the need for more expensive labor.

The shape of the pharmacy labor cost curve supports the model of process based adoption. It appears that as a hospital seriously implements CPOE, pharmacy labor costs rise. Rough and Melroy (2009) suggested that this is due to the fact that pharmacists become more involved in the process of care when all the information is readily available to them. A portion of the increase in costs in the 51-90% use category can be explained by the need to run and reconcile the two different medication ordering processes. The cost of labor then falls in the 91-100% category because the need for reconciliation in the process is greatly reduced.

A different pattern is seen in the clinical environment than is visible in the pharmacy environment. Labor costs seem to fall in the 51-90% usage category. This might be explained in reduced labor costs. Most likely, the early adopters of the system are doctors who are enthusiastic and capable of using the CPOE system. This can potentially reduce the need for nurses and other clinical staff to call physicians to interpret hand writing. It also requires less verification and correction of out-of-bounds orders as many of these systems have warnings for inappropriate medications. In the final stage of usage, labor costs rise significantly. One explanation is that the physicians who don't need significant training and coaching have already adopted. The last group of physicians to adopt will need significant coaching and are possibly resistant to use. The clinical staff and nurses may be required to provide this training and coaching. A second explanation of the higher clinical cost is that the hospital may be expending resources (in additional nurse support) in the clinical environment to get buy-in from physicians who are not part of the hospital pay structure. The hospital may need to provide this kind of on-site, just-in-time support because physicians cannot be forced to attend training.

In another sense, these findings coincide with those of earlier work on process-based automation. The effects on pharmacy and clinical salaries did not happen until the process was being used for over half of the orders. In the earlier work a large portion of cost reduction did not happen until the process was fully automated. Although use and amount of automation are not the same variable, the two are correlated as evidenced by the selection equation in the analysis.

The quality curve is different from the costs curves in that quality results happen quickly. In general, hospitals with any amount of use have higher quality than hospitals that do not use electronic order entry. It may be that hospitals which implement CPOE first implement it in departments or areas of the hospital which are most prone to EBM errors. When this is the case, one would expect the largest return on investment from use of CPOE in these first trouble areas. Further use of CPOE may have only marginal returns on quality.

Two of the quality measures showed relationships with 91-100% use. EBM quality measures related to acute myocardial infarction or heart attack increased significantly with full use of the electronic medication entry while measures related to pneumonia showed a significant decrease. Further research may be able to discover whether these two medical conditions are on average the last to be moved from the manual to the automated process. The differences in the effects of these systems on the two conditions may relate to the differences in treatment of the conditions. In cases of heart attack, treatments must be administered within minutes of the infarction to be most effective (Boersma et al. 2003). Poll, and Opal (2009) describe pneumonia quite differently. Although some cases are quick on-set, most patients experience many symptoms and gradual onset. Treatments are not described in terms of minutes from onset, but just in terms of which drugs, antibiotics, and other treatments may be used.

Beyond the unexpected condition-specific quality related findings, there are several other questions and limitations that need to be answered. This study covers only one year of CPOE usage. In the next few years data will become available to allow cost and usage relationships to be tested over time in the hospital environment. Experience, which has often been calculated in terms of automation dates, could then be calculated in terms of use. Further, the research question refers to usage of the IT in the process. CPOE usage appears to be an effective measurement of the usage of IT in the medication management process. However, other points of measurement could be clinical documentation, pharmacy order management, pharmacy inventory management, and the percent of orders recorded using the EMAR. Future work should also seek out these measures to develop a full picture of use of the IT in the process.

One potential limitation of this data is that there are over 170 hospitals which have not implemented CPOE but indicate that all of their orders are placed electronically. This may be done through other electronic systems or through CD.

Considering this to be noise, these hospitals could be dropped. On the other end of the spectrum there are 61 hospitals which indicate CPOE has been completely implemented in the whole hospital but also indicate that none of the orders are input electronically. The analysis was conducted again after dropping these hospitals. Results were almost identical except that pharmacy salaries per patient day appeared to increase from the 51-90% use to 91-100% use instead of the drop observed in the above data. The use variable provided by the IT supplement to the AHA annual survey does not appear to directly measure CPOE usage. There are several ways for an order to be entered electronically. Although the measure used in this study is effective for answering the research question, future work should seek measures more directly related to CPOE usage.

This study has implications for both researchers and IT decision makers. The analysis further validates the model of process-based automation. Accounting for all of the IT in the process is important for accurate estimation of the effects of IT and IT usage on outcome variables. The results demonstrate that IT and organizational factors affect usage. Usage in turn affects performance. In academic research it is therefore vital to account for usage where possible.

Decision makers must evaluate both the technical environment in which new systems will operate as well as the organizational environment. According to the analysis of over 2000 acute care hospitals, hospitals which do not use the system will not experience the quality gains expected. Further, decision makers must recognize that automation of the business process does not always reduce costs.

This analysis supports the conclusion that labor costs generally rise with the automation of the business process.

One finding of interest to both researchers and practitioners is seen when considering both quality and labor costs simultaneously. Because costs seem to rise with 100% use of CPOE and the largest jumps in quality happen in the 1-25% usage category, an optimal point of use may not be 100%. This optimal point will vary per industry, organization, and process. Researchers should develop the model of process-based automation or seek other theories to provide heuristics to decision makers on where to find this optimum point.

5.6. Key findings and implications of chapter 5

This study answers the question: Does system use play an intermediate role between systems implementation and cost and quality outcomes? To answer this question, the study developed a model of process-based automation to include IT usage. Data for the analysis were drawn from the American Hospital Association, Center for Medicare and Medicaid Services, and the Hospital Quality Alliance. The cross sectional data include more than 2000 U.S. acute-care hospitals in 2007. A Heckman selection bias correction is used to more accurately estimate the effects of usage on process performance. The analysis largely supports the model.

This study makes several contributions. First, it extends the model of process-based automation by confirming the mediating role of IT usage. The original model assumes a direct relationship between process automation and process outcomes. The analysis supports the model that IT factors impact usage and that usage impacts process outcomes. Second, this study provides insight into the effects of actual IT usage at the process level. Until the merging of these data sets, this detail has been almost impossible to observe in the healthcare industry. The inclusion of usage in the model provides a better lens through which to judge the impact of automation on the medication management process.

Chapter 6. Summary and Conclusions

The essays included in this dissertation all focus on the value created by a set of systems as defined by the business process. A model of process-based automation is developed using theory and concepts from literature on complementary innovations, business processes, information systems, value of IT, and healthcare. The three studies each propose and answer separate questions which address the more general question: How do sets of systems as defined by the business process create cost and quality improvements? All three studies are completed in the context of the healthcare industry. The analyses focus particularly on the medication management process within acute-care hospitals.

6.1. Summary of Findings

The first study answers the question: Does the order of automation of the tasks in the process have an effect on cost outcomes? The order of automation is compared to two hypothesized patterns. The Levenshtein distance (Levenshtein 1966) is used to compare observed patterns to hypothesized patterns. The hypothesized patterns are tested against 137 U.S. acute care hospitals. Patterns of adoption are calculated from 10 years of the HIMSS Analytics database. Hospitals which have more closely followed the organizational pattern of adoption are associated with better financial outcomes. The analysis suggests that the effects of the order of automation diminish as the whole process is automated.

The second study answers the question: Does the automation continuity or discontinuity of the business process have an impact on cost and quality? The study develops a measure of process automation discontinuity which focuses on the number of connections in the process which change from manual to automated and from automated to manual. The model suggests that discontinuities should lead to higher costs and lower quality. Theory further predicts that lower costs should be experienced by hospitals which implement the front end of the process as compared to those that implement the back end of the process. The predictions are tested using a panel data set of 341 California hospitals measured for 11 years. The data are analyzed using a fixed-effects model. Results show that discontinuities in automation are associated with higher clinical costs and higher numbers of adverse drug events. The analysis also shows that automation at the beginning of the process is associated with lower clinical costs than automation at the end of the process. Further supporting the need to observe all the systems in the process, most cost savings are not seen until the whole process is automated.

The final study answers the question: Does system use play an intermediate role between systems implementation and cost and quality outcomes? The model of process-based automation suggests that value is created through the use of the automated process. The measure of systems usage is provided by the American Hospital Association for the year 2007. Due to a selection bias, a Heckman selection correction (Heckman 1979) model was implemented. The analysis shows that IT factors such as vendor and extent of automation impact use. Use in turn has a very strong relationship with process labor costs and evidence-based medicine quality measures. The relationships between use and labor costs suggests that in the highest levels of automation hospitals may be expending more in clinical costs to coerce independent doctors to use the electronic order entry systems. The analysis also suggests that managing both the automated and manual processes is more costly in terms of pharmacy salaries than is managing one or the other.

Together these three studies develop the model of process-based automation which strongly supports the notion that complementary systems create value through relationships and roles defined by the business process. Systems which are entry points to the process provided more effective controls of variation in the process than those at the end of the process. After accounting for the amount of automation in the process, when systems are automated contiguously, more benefits are realized than when gaps in automation exist. Faster returns are realized when piece-meal automation occurs in accordance with the organizational structures of the business process. Finally, use of the automated process is a key factor in realizing benefits from investments in process IT.

6.2. Future Research

This research lays the foundation for a program of research which continues to investigate the effects of process IT and characteristics of process IT on process outcomes. The concepts tested in the second study related to discontinuity are very closely related to integration of the process systems. Many organizations struggle with questions of vendor behavior and vendor lock-in. Future research should investigate vendor effects from the perspective of both the vendor and the client organization. From the vendor's point of view, how much of the process must be automated by a vendor before the client is much more inclined to complete the automation of the process using the vendor's solutions? From the client's perspective, what factors affect the ability of an organization to profit from best-of-breed implementation or single vendor solutions? Is there value-at-risk in automating incremental stages of the process using a specific vendor?

The model of process-based automation clearly shows that understanding organizational boundaries crossed by the business process is critical to developing an automation strategy. Some organizations may have better financial outcomes associated with the organizational pattern of adoption such as the hospitals included in the first study. Other organizations may benefit more from an operational pattern of adoption. What organizational benefits dictate which of these patterns are more beneficial?

Chapter 5 suggests that the benefits and costs of use are related to the type of users in the organization. Future work could provide much needed guidance to decision makers as to the amount of usage required for optimal outcomes. The analysis suggests that much more expense is incurred by coaxing two types of users to use the system: independent users having "arms-length" relations with the organization and users that are less computer literate. In the context of this study quality measures across the board increased with minimal use. These two points together suggest that the optimal point of use may not be full automation.

The first study uses a measure based on the Levenshtein distance which allows for adoption of sequences in the same period. Although this measure is insightful, it is not a perfect measure for all patterns of adoptions. The sample data set had to be limited to those hospitals which automated the medication management systems in a pure sequence. Though much development is still required to appropriately apply the tools, other options exist. Social networking tools related to nodes and edges may be a starting point for the development of such a measure. Several other adoption phenomena are not accounted for in this work. This analysis looks only at sequential adoption. Co-adoption and big-bang techniques may also be related to financial outcomes because of the necessity to coordinate all actors (Markus et al. 2000), mass customization of vendor software (Bingi et al. 1999), and/or the adaptation of large groups of processes to fit the system (Barua et al. 1996).

The second study used a measure which could be considered a proxy for integration. Better measures of integration should lead to stronger results. Further studies in this context should consider taking into account intersecting processes as well as the main process (such as pharmacy inventory management and diagnosis and inpatient care processes). The second study and first study together suggest that different outcomes may be associated with piece-meal and big-bang projects. Agarwal et al. (2010) noted that this question is still a relevant issue, particularly in healthcare. The model of process-based automation could easily be extended to suggest how these two options will differ in terms of cost and quality improvements.

The model of process-based automation must also be tested in other contexts. Strong support for the model is provided in the context of healthcare by these three studies. The model is developed to fit the more general context of all business processes in which multiple systems interact. Future work should consider financial or airline industries as candidate contexts. These industries, like healthcare are well regulated and offer potential data sets on the amount of usage.

6.3. Implications

The model of process-based automation has implications for the healthcare industry, for IT decision makers, and for future research. From the healthcare perspective, this work suggests that quality improves with the implementation of these systems. However, it should not be expected that these systems will reduce overall labor costs. In some cost centers at certain points of automation and usage, there are reductions in labor cost. In the overall picture of automation, labor costs rise. Current national discussion focuses around complete automation of hospital processes particularly as it relates to patient care. While this work cannot make inferences about national welfare, it does suggest that hospitals will have lower costs and still obtain large quality increases through partial use of electronic medication entry systems. Use of the automated process for 100% of the orders may not be the most optimal when the hospital works with a larger portion of independent physicians and physicians averse to using hospital computer systems.

The implications of the model of process-based automation are most relevant to IT decision makers, particularly those creating long-term strategies for automating business processes. After automating tasks which are sources of extreme variance, the quickest returns on investment will be found in implementation of one of two strategies or in a combination of the two. The first is that contiguous automation is critical to realizing returns from complementarities in systems. Where possible, the next investment should be in tasks adjacent to previously automated tasks and these systems should be integrated. The second is that automation at the front end of the process is more valuable than at the back end of the process. This is largely due to the fact that out-of-bounds variation created in the beginning stages of the process will be more expensive than the variation created in the latter stages of the process. The value of the initial systems is also due to the fact that data entry can happen once at the beginning of the process reducing the need for reconciliation further down the process.

These studies offer several implications for future research. First is that research evaluating the value of IT must consider the whole set of applications which automate the business process. This is particularly important when the outcome variable includes process-level outcomes. The second implication is that the role of the system in the process matters. Entry systems, boundary spanning systems, and back-end control systems all have different effects on cost and quality. Finally, evaluation of the value of information technology at the process level requires an evaluation of usage of the automated process. In some contexts it may be possible to assume that the automated systems are used for all transactions. For the majority of processes, the percent of transactions which are processed through the automated system will not be 100%. Further, the level of usage will be related to both IT and organizational factors.

6.4. Conclusions

This research has made important contributions to the current body of research on information systems, IT value, and business process automation. The basic premise of the model is that the business process defines complementarities and roles of the systems which interact within the process. The second contribution is two measures of process automation characteristics. One measure uses the Levenshtein distance to measure the distance between observed and hypothesized patterns. The other measures the amount of automation discontinuity within a business process. The third main contribution of this work is the verification of the model of process-based automation using three large data sets.

The main finding of this research is that the business process is a powerful tool for determining where complementarities exist and how information systems create value. This finding is tested using data sets pertaining to acute care hospitals in the US from 1998 to 2008. The studies contained in this dissertation lay the foundation for a large program of study related to strategies for automating end-to-end processes.

Chapter 7. References

Abbott, A., and J. Forrest. 1986. Optimal Matching Method for Historical Sequences. *Journal of Interdisciplinary History* **16**(3) 471-494.

Abbott, A., and A. Hrycak. 1990. Measuring Resemblance in Sequence Data: An Optimal Matching Analysis of Musicians' Careers. *The American Journal of Sociology* **96**(1) 144-185.

Agarwal, R., G. Gao, C. DesRoches, and A.K. Jha. 2010. The digital transformation of healthcare: Current status and the road ahead. *Information Systems Research* **21**(4) 796-809.

Alter, A.E. 2007. Business Alignment: The Eternal Priority. *CIO Insight* March 22, 2007.

Angst, C.M., S. Devaraj, and C.C. Queenan. 2011. Performance effects related to the sequence of integration of healthcare technologies. *Production and Operations Management* **Forthcomming**.

Arellano, M., and S. Bond. 1991. Some tests of the specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies* **58**(2) 277-297.

Barua, A., C.H.S. Lee, and A.B. Whinston. 1996. The calculus of reengineering. *Information Systems Research* **7**(4) 409-428.

Barua, A., and A.B. Whinston. 1998. Decision support for managing organizational design dynamics. *Decision Support Systems* **22**(1) 45-58.

Bates, D.W. 2000. Using Information Technology to Reduce Rates of Medication Errors in Hospitals. *British Medical Journal (BMJ)* **320** 788-308.

Bates, D.W., and A. Gawande. 2003. Patient Saftey: Improving Patient Safety with Information Technology. *New England Journal of Medicine* **348**(25) 2.

Battisti, G., M.G. Colombo, and L. Rabbiosi. 2004. Path dependency and causality testing in the presence of complementarity effects: An application to the adoption sequence of an IT related innovation and new work practice. *Proc. 15th (EC)-squared Conference*, Marseille, France.

Bhosle, M., and S.S. Sansgiry. 2004. Computerized physician order entry systems: Is the pharmacist's roal justified? *Journal of the American Medical Informatics Association* **11**(2) 125-126.

Bingi, P., M.K. Sharma, and J.K. Godla. 1999. Critical Issues Affecting an ERP Implementation. *Information Systems Management* **16**(3) 7-14.

Boersma, E., N. Mercado, D. Poldermans, M. Gardien, J. Vos, and M.L. Simoons. 2003. Acute myocardial infarction. *The Lancet* **361**(9360) 847-858.

Bresnahan, T.F., E. Brynjolfsson, and L.M. Hitt. 2002. Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm- Level Evidence. *The Quarterly Journal of Econometrics* **117**(1) 339-376.

Brooke, B.S., F. Dominici, M.A. Makary, and P.J. Pronovost. 2009. Use Of Beta-Blockers During Aortic Aneurysm Repair: Bridging The Gap Between Evidence And Effective Practice. *Health Affairs* **28**(4) 1199-1209.

Brzinsky-Fay, C., U. Kohler, and M. Luniak. 2005. Sequence Analysis with Stata. *The Stata Journal* **6**(4) 435-460.

Bucklin, L.P., and S. Sengupta. 1993. The co-diffusion of complementary innovations: supermarket scanners and UPC symbols. *Journal of Product Innovation Management* **10**(2) 148-160.

Burlton, R.T. 2001. *Business process management: profiting from process.* Sams, Indianapolis, IN.

Buzacott, J.A. 1996. Commonalities in reengineered business processes: Models and issues. *Management Science* **42**(5) 768-782.

Cattell, R.B. 1966. The scree test for the number of factors. *Multivariate Behavioral Research* **1**(2) 245-276.

Chiburis, R., and M. Lokshin. 2007. Maximum likelihood and two-step estimation of an ordered-probit selection model. *The Stata Journal* **7**(2) 167-182.

Colombo, M.G., and R. Mosconi. 1995. Complementarity and cumulative learning effects in the early diffusion of multiple technologies. *Journal of Industrial Economics* **43**(1) 13-48.

Culler, S.D., J.N. Hawley, V. Naylor, and K.J. Rask. 2007. Is the availability of hospital IT applications associated with a hospital's risk adjusted incidence rate for patient safety indicators: results from 66 Georgia hospitals. *Journal of Medical Systems* **31**(5) 319-327.

Cutler, D.M., N.E. Feldman, and J.R. Horwitz. 2005. U.S. adoption of computerized physician order entry systems. *Health Affairs* **24**(6) 1654-1663.

Daft, R.L. 1978. A dual-core model of organizational innovation. *Academy of Management Journal* **21**(2) 193-210.

Davamanirajan, P., R.J. Kauffman, C.H. Kriebel, and T. Mukhopadhyay. 2006. Systems design, process performance, and economic outcomes in international banking. *Journal of Management Information Systems* **23**(2) 65-90.

Davenport, T.H., and J.E. Short. 1990. The new industrial engineering: Information technology and business process redesign. *Sloan Managemetn Review* **31**(4) 11-21.

Davidson, R., and J.G. MacKinnon. 1993. *Estimation and Inference in Econometrics.* Oxford University Press, New York, NY.

Davis, F.D. 1985. A technology acceptance model for empirically testing new end-user information systems: Theory and results. Massachusetts Institute of Technology.

Davis, K., C. Schoen, and K. Stremikis. 2010. Mirror, mirror on the wall: How the performance of the U.S. health care system compares internationally, 2010 Update, The Commonwealth Fund.

Devaraj, S., and R. Kohli. 2000. Information technology payoff in the health-care industry: a longitudinal study. *Journal of Management Information Systems* **16**(4) 41-67.

Devaraj, S., and R. Kohli. 2003. Performance impacts of information technology: is actual usage the missing link? *Management Science* **49**(3) 273-289.

Elixhauser, A., and P. Owens. 2007. Statistical Brief #29: Adverse drug events in U.S. hospitals, 2004, Healthcare Cost and Utilization Project (HCUP).

Furukawa, M., T.S. Raghu, and B.M. Shao. 2010a. Electronic medical records and cost efficiency in hospital medical-surgical units. *Inquiry* **47**(2) 110-123.

Furukawa, M., T.S. Raghu, and B.M. Shao. 2010b. Electronic medical records, nurse staffing and nurse-sensitive patient outcomes: Evidence from the national database of nursing quality indicators. *Medical Care Research and Review* **Forthcoming**.

Furukawa, M., T.S. Raghu, and B.M. Shao. 2010c. Electronic medical records, nurse staffing, and nurse sensitive patient outcomes: Evidence from California hospitals. *Health Services Research* **45**(4) 941-962.

Furukawa, M., T.S. Raghu, T.J. Spaulding, and A. Vinze. 2008. Adoption of health information technology for medication safety in U.S. hospitals. *Health Affairs* **27**(3) 865-875.

Gans, D., J. Kralewski, T. Hammons, and B. Dowd. 2005. Medical groups' adoption of electronic health records and information systems. *Health Affairs* **24**(5) 1323.

Goldratt, E.M., and J. Cox. 1984. *The Goal: A Process of Ongoing Improvement.* North River Press, Great Barrington, MA.

Golob, T.F., and A.C. Regan. 2002. Trucking industry adoption of information technology: a multivariate discrete choice model. *Transportation Research Part C* **10**(3) 205-228.

Grover, V., S.R. Jeong, W.J. Kettinger, and J.T.C. Teng. 1995. The implementration of business process reengineering. *Journal of Management Information Systems* **12**(1) 109-144.

Hammer, M., and J. Champy. 1993. *Reengineering the corporation: A manifesto for business revolution.* Harper Business Editions, New York, NY.

Hayton, J.C., D.G. Allen, and V. Scarpello. 2004. Factor retention decisions in exploratory factor analysis: a tutorial on parallel analysis. *Organizational Research Methods* **7**(2) 191-205.

Heckman, J.J. 1979. Sample selection bias as a specification error. *Econometrica* **47**(1) 153-161.

Hitt, L.M., and E. Brynjolfsson. 1996. Productivity, business profitability and consumer surplus: Three different measures of information technology value. *Management Information Systems Quarterly* **20**(2) 121-142.

Holtz-Eakin, D., W. Newey, and H.S. Rosen. 1988. Estimating vector autoregressions with panel data. *Econometrica* **56**(6) 1371-1395.

Jha, A.K., C.M. DesRoches, E.G. Campbell, K. Donelan, S.R. Rao, T.G. Ferris, et al. 2009. Use of Electronic Health Records in U.S. Hospitals. *The New England Journal of Medicine* **360**(16) 1628-1638.

Karahanna, E., D.W. Straub, and N.L. Chervany. 1999. Information technology adoption across time: a cross-sectional comparison of pre-adoption and post-adoption beliefs. *Management Information Systems Quarterly* **23**(2) 183-213.

Karshenas, M., and P.L. Stoneman. 1993. Rank, stock, order, and epidemic effects in the diffusion of new process technologies: an empirical model. *The RAND Journal of Economics* **24**(4) 503-528.

Kettinger, W.J., J.T.C. Teng, and S. Guha. 1997. Business process change: a study of methodologies, techniques, and tools. *Management Information Systems Quarterly* **21**(1) 55-80.

Klein, M. 1995. 10 Principles of reengineering. *Executive Excellence* **12**(2) 20.

Lawrence, D. 2009. The Field Narrows. *Healthcare Informatics* **26**(8) 14-16.

Lee, H.L., V. Padmanabhan, and S. Whang. 1997. Information distortion in a supply chain: the bullwhip effect. *Management Science* **43**(4) 546-558.

Levenshtein, V. 1966. Binary codes capable of correcting deletions, insertions and reversals. *Soviet Physics Doklady* **10**(8) 707-710.

Li, L., and W.C. Benton. 2006. Hospital technology and nurse staffing management decisions. *Journal of Operations Management* **24**(5) 676-691.

Malone, T.W. 1987. Modeling coordination in organizations and markets. *Management Science* **33**(10) 1317-1332.

Markus, M.L. 1983. Power, politics, and MIS implementation. *Communications of the ACM* **26**(6) 430-444.

Markus, M.L. 2004. Technochange management: using IT to drive organizational change. *Journal of Information Technology* **19**(1) 4-20.

Markus, M.L., and D. Robey. 1988. Information Technology and organizational change: Causal Structure in Theory and Research. *Management Science* **34**(5) 583-598.

Markus, M.L., C. Tanis, and P.C. Van Fenema. 2000. Multisite ERP Implementations. *Communications of the ACM* **43**(4) 42-46.

McCue, M.J. 2011. Association of market, organizational and financial factors with the number, and types of capital expenditures. *Health Care Management Review* **36**(1) 67-77.

McNair, P.D., H.S. Luft, and A.B. Bindman. 2009. Medicare’s Policy Not To Pay For Treating Hospital-Acquired Conditions: The Impact. *Health Affairs* **28**(5) 1485-1493.

Menachemi, N., A. Chukmaitov, C. Saunders, and R.G. Brooks. 2008. Hospital quality of care: does information technology matter? The relationship between information technology adoption and quality of care. *Health Care Management Review* **33**(1) 51-59.

Menachemi, N., N. Hikmet, A. Bhattacherjee, and R.G. Brooks. 2007. The effect of payer mix on the adoption of information technologies by hospitals. *Health Care Management Review* **32**(2) 102-110.

Mumford, E. 1994. New treatments or old remedies: is business process reengineering really socio-technical design? *Journal of Strategic Information Systems* **3**(4) 313-326.

Needleman, S., and C. Wunsch. 1970. A general method applicable to the search for similarities in the amino acid sequence of two proteins. *Journal of Molecular Biology* **48**(3) 443-453.

Peppard, J., and P. Rowland. 1995. *The essence of business process reengineering*. Prentice-Hall, New York, NY.

Poll, T.v.d., and S.M. Opal. 2009. Pathogenesis, treatment, and prevention of pneumococcal pneumonia. *The Lancet* **347**(9700).

Poon, E.G., D. Blumenthal, T. Jaggi, M.M. Honour, D.W. Bates, and R. Kaushal. 2004. Overcoming barriers to adopting and implementing computerized physician order entry in U.S. hospitals. *Health Affairs* **23**(4) 184-190.

Raghu, T.S., B. Jayaraman, and H.R. Rao. 2004. Toward an integration of agent- and activity-centric approaches in organizational process modeling: incorporating incentive mechanisms. *Information Systems Research* **15**(4) 316-335.

Raghu, T.S., and A. Vinze. 2007. A business process context for knowledge management. *Decision Support Systems* **43**(3) 1062-1079.

Rough, S., and J. Melroy. 2009. Pharmacy Information Systems. *The Pharmacy Informatics Primer*. D. Dumitru (ed.) American Society of Health-System Pharmacists, Bethesda, MD.

Rupp, R.O., and J.R. Russel. 1994. The golden rules of process redesign. *Quality Progress* **27**(12) 85-92.

Schumacher, E.J. 2002. Technology, skills, and health care labor markets. *Journal of Labor Research* **23**(3) 397-415.

Silverstein, A.B. 1987. Note on the parallel analysis criterion for determining the number of common factors or principal components. *Psychological Reports* **61**(2) 351-354.

Smith, M.H., and D. Weil. 2005. Ratcheting up: linked technology adoption in supply chains. *Industrial Relations* **44**(3) 490-508.

Sobel, M.E. 1982. Asymptotic confidence intervals for indirect effects in structural equations models. *Sociological methodology*. S. Leinhart (ed.) Jossey-Bass, San Francisco, CA.

Stoddard, D.B., and S.L. Jarvenpaa. 1995. Business process redesign: Tactics for managing radical change. *Journal of Management Information Systems* **12**(1) 81-107.

Stoneman, P., and M.-J. Kwon. 1994. The diffusion of multiple process technologies. *Economic Journal* **104**(423) 420-431.

Swanson, E.B. 1994. Information systems innovation among organizations. *Management Science* **40**(9) 1069-1092.

Teng, J.T.C., V. Grover, and K.D. Fiedler. 1994. Business process reengineering: charting a strategic path for the information age. *California Management Review* **36**(3) 9-31.

Tucker, A.L., and S.J. Spear. 2006. Operational failures and interruptions in hospital nursing. *Health Services Research* **41**(3) 643-662.

Wozniak, G.D. 1984. The adoption of interrelated innovations: a human capital approach. *Review of Economics and Statistics* **66**(1) 70-79.

Wu, R.C., and S.E. Straus. 2006. Evidence for handheld electronic medical records in improving care: a systematic review. *BMC Medical Informatics and Decision Making* **6**(26).

Yu, F.B., N. Menachemi, E.S. Berner, J.J. Allison, N.W. Weissman, and T.K. Houston. 2009. Full implementation of computerized physician order entry and medication-related quality outcomes: a study of 3364 hospitals. *American Journal of Medical Quality* **24**(4) 278-286.