

Information technology and hospital performance*

An econometric analysis of costs and quality

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Executive Summary

Healthcare delivery organizations face a chorus of exhortations to invest in healthcare IT. Advocates include President Bush, industry groups, technology vendors, and others. Various claims usually characterize the need for investment as urgent, the time as ripe, and the paybacks as substantial. Yet skepticism remains, at least partially because strong evidence of benefits—let alone a return on investment—is difficult to find. Two authoritative studies have concluded that the lack of a substantive business case for investment in clinical systems was a key factor in organizations' resistance to invest.

PricewaterhouseCoopers and researchers at the Wharton School of the University of Pennsylvania collaborated on a study to investigate healthcare IT investment. We had two objectives: first, to assess the relationships between IT investment and other measures of hospital performance by using advanced statistical and econometric techniques; and second, to establish whether such relationships support the assertion that investment in IT by US hospitals actually enhances organizational performance.

The study used data from a sample of almost 2,000 US hospitals. To reach our results, we relied on techniques derived from studies published in peer-reviewed, academic publications during the past 10 years. These methods are more capable of exploring claims that IT investment causes economic benefit. Simple correlation studies or single-institution case studies are subject to criticisms that reduce the validity of causal inferences. Our multiyear data panel also allowed us to explicitly test for the effects of IT investment that take a year or more to appear in hospital performance data, an outcome that other studies have found in healthcare and other industries.

Our study reveals an important and statistically significant relationship between IT capital investment and hospital cost efficiency. At levels of IT that most hospitals can aspire to reasonably quickly, our study shows evidence of real cost reductions. At lower levels of IT capital investment, however, additional IT investment seems to be associated with increased hospital operating expenses. In hospitals that have reached a threshold level, increases in IT capital investment are associated with lower hospital operating costs. For-profit hospitals generally appear to gain larger cost reductions from their investments, and they gain these benefits at lower levels of IT investment. Another noteworthy result indicates that mortality rates adjusted for risk and case mix are also affected by IT investment; hospitals that invest more in IT demonstrate lower mortality rates. Although mortality is not an ideal proxy measure for quality of care, it can highlight areas worthy of additional exploration.

Hospitals should consider the applicability of these findings to their own investment strategies, and they should recognize that depending on where they are on the scale of IT investment, the benefits may take significant time and effort to realize. Healthcare IT vendors may need to adjust their sales messages to better take into account the starting point for hospitals contemplating acquisition of IT products, and vendors may need to invest more aggressively to ensure that appropriate process redesign is a part of their implementation programs. Policymakers should take note of this powerful new evidence that IT investment has demonstrable effects, but be aware that some hospitals may have a long way to go for those effects to represent a return on investment.

Key Findings

The following is a summary of our findings.

Findings from Previous Studies

US hospital executives face pressures to automate processes of care. Healthcare IT is sometimes described using terms that make it sound like a panacea—the solution to all healthcare’s problems. The published literature on the impact of IT on hospitals, however, still leaves significant unanswered questions regarding the real benefits of IT.

IT has significant effects in other industries, but equivalent studies have not been conducted for healthcare. We found extensive evidence that IT has significant effects in industries other than healthcare; substantial returns on investment are apparent in several studies. We did not find an equivalent body of studies in healthcare.

The impact of IT increases over time. In more recent empirical studies of productivity changes associated with IT investments, a key finding is that organizational impact takes time. That is, for any given IT investment, the immediate impact on performance is smaller than the impact after three or four years. Researchers suggest that this time lag is associated with organizations’ slow achievement of process changes after the installation of new IT applications.

Data does not support generalized conclusions. The most recent and authoritative sources on the impact of IT on hospitals usually did not support generalized conclusions about the costs and benefits of healthcare IT. Studies that have positive conclusions tend to have been published by only a few organizations that are not always considered representative of most other hospitals.

A handful of econometric studies have been published, but none provide the level of rigor or conclusiveness required to fully and directly support the case for investment. Previous research examining the relationship between IT investment and hospital performance (both cost and quality) used techniques that limit the ability to infer causality and also used weak measures of IT investment.

Econometric techniques are necessary for full understanding. Prior research from industries other than healthcare indicates that econometric techniques, rather than simple correlative statistical studies, are necessary to fully understand the relationship between IT investment and performance. We found that more explanatory power can be developed by using established economic and statistical techniques to model the impact of IT on hospitals.

Findings from the PricewaterhouseCoopers and Wharton School Study

IT investment significantly affects business performance in US hospitals. Our statistical evidence and study results suggest that higher levels of IT investment are associated with reduced operating expenses in acute care hospitals, but only after hospitals have reached a threshold level of investment—which we call a tipping point. At lower initial levels of IT investment, operating expenses rise with incremental investment.

Not all hospitals gain the same benefits from their IT investments. Some hospitals appear to gain greater reductions in operating expenses in response to IT investments than others. We found that in return for their IT usage, not-for-profit hospitals appear to experience smaller cost-reduction effects than for-profit hospitals and reach the tipping point at higher levels of IT capital.

Cost reductions occurred in the same year as the IT acquisition. In a previous PricewaterhouseCoopers and Wharton School study, we found that hospitals that have invested in IT accrue more benefits over time. This effect should cause the impact of investments in not-for-profit hospitals to shift from appearing to be purely cost increasing to being mildly cost reducing. In this updated analysis, we found that hospitals that have invested in IT reported reduced expenses in the same year as the IT acquisition, and, in contrast with our prior research, we found only limited evidence that the effects of IT increased over time.

Hospitals that have a more complete IT infrastructure tend to have a lower mortality rate (adjusted for risk and case mix). The effect is independent of costs per bed. Our exploration of the impact of IT investment on mortality rates included hospitals that have different cost and IT capital profiles.

More research is needed to substantially deepen the understanding of the relationship between IT investment and quality of care. Although industry literature includes encouraging findings, they are usually case studies of single institutions. Such research is hampered by a lack of good time-series data documenting hospital quality. The situation is changing, however, as efforts to measure quality on a national basis have become better established.

Nationally available data sources enabled us to assess the impact of IT investment on only the first three of the six Institute of Medicine (IOM) quality aims (safety, effectiveness, and efficiency). The quality aims promulgated by the IOM are characteristics of the health system to which the industry should be aspiring. Effective assessment of other aspects of the US healthcare system—or individual hospital—performance will require additional information that is not yet fully and readily available nationally. The research we have undertaken here—including the development of an economic model with which to better understand the impact of IT investment—could be seen as a starting point. Testing the forecasts of this model in the future will be possible, because hospitals in various stages of adoption have been identified.

Recommendations

We advise hospital executives, healthcare IT vendors, and policymakers to consider the following actions as they develop their strategy.

Recommendations for Hospital Executives

Consider a hospital's IT capital starting position and then use this study's empirical findings to anticipate the impact of IT investments on hospital operating costs. Many hospitals will be at a point on the IT investment curve that will limit the financial payback from the investment. Quality improvements may bolster the argument for investment, but supporting evidence is still in a formative stage. Hospital executives should not justify expensive new IT investments solely on the assumption that these investments will deliver large returns. A more effective approach may be to justify moving along the curve to a position where future IT investments pay for themselves and also position the hospital for quality improvements.

Use the range of returns actually achieved to set expectations for returns that an organization can gain from its investment in IT. Some hospitals will gain greater cost-reduction benefits than might be expected from our results; others may experience less. Hospital executives can leverage the models developed in this research to establish reasonable, empirically based expectations of their return on investment (ROI) from IT investments. Although the mortality results are relatively modest, their statistical reliability is strong. Basing decisions on the results of analyses for both mortality and cost efficiency may be more persuasive than the results that relate to cost efficiency alone.

Benchmark against these findings to help determine how effectively a hospital leverages the IT infrastructure already in place. Although this study was not able to include measures of process change in its analysis, there is good reason (on the basis of studies in other industries) to believe that hospitals that have above-average IT investments have large, latent opportunities for cost efficiencies that could be released with process reengineering. Hospitals will need to reexamine their commitment to and investment in process change—both business and clinical—if they hope to capture more benefit from IT investments.

Establish the opportunity for improvement by comparing a hospital's costs with similar hospitals at the same position on our IT Capital Index scale.

The econometric model we developed for this study can provide an estimate of overall IT effectiveness for a particular hospital relative to the other hospitals in the sample. Executives can, for example, decide whether further IT investments are warranted before process improvements are made, and vice versa.

Recommendations for Healthcare IT Vendors

Benchmark company promises to hospital executives against the reality of what is currently being delivered in hospitals. IT vendors selling into the hospital market must acknowledge that promises of high ROI are increasingly difficult to support. This study and other empirical analyses using data from more than half of all US hospitals still require an explicit appeal to additional factors not included in this study before vendors can make reasonable assertions of high ROI for IT investments. The exception is administrative systems, which show clear evidence of financial returns. Vendors may need to consider a more complex sales proposition, not simply an ROI argument.

Tailor IT investment messaging to hospitals. IT vendors may need to adjust IT investment messaging to hospitals by creating a tailored message that explicitly accounts for the current state of IT investment at a specific hospital. Vendors should be forthright when selling to hospitals that are in the early phases of IT investment, acknowledging that these hospitals face a long road ahead before gaining returns from subsequent phases of IT investment.

Invest in more expansive process redesign and change management services capabilities and work more closely with integration partners to help hospitals maximize the use of IT.

Implementing IT from a full organizational and process change perspective is in hospitals' direct interest more than ever, especially as data and analyses of the type demonstrated in this study establish that simply buying and installing has modest effects.

Recommendations for Policymakers

Tone down strident messages to hospital executives that they are intentionally delaying the obvious choice to invest in IT. Such investments create complex interplays of value and extra cost. Smaller hospitals at the low end of the investment curve may face significant challenges in investing because of the increased operating expenses associated with additional IT, especially in the context of significant national cost pressures. If further research continues to validate the model and findings of this study, a new policy framework should be developed that explicitly acknowledges the lack of a short- or medium-term business case for hospitals currently low on the IT Capital Index scale.

Consider accelerating the initiatives that include pay-for-performance compensation schemes. Because of the modest cost-reduction impact demonstrated by this study, compensating hospitals for higher quality will, if our preliminary results are validated with more broad-based studies, create far more incentive for executives to invest in IT than a focus on the traditional business metric of cost avoidance.

Introduction

The business case for healthcare IT is often stated as a foregone conclusion: improved healthcare quality, reduced costs, and enhanced productivity. By now, this list of perceived benefits is well known among policymakers, technology vendors, hospital executives, and even consumers. Outside healthcare, the relationship between IT investment and increased productivity has been documented in macroeconomic (data aggregated across all industries) and microeconomic (at the company level in select industries) studies, including seminal studies at the Massachusetts Institute of Technology.

Likewise, case studies have demonstrated measurable effects of IT on a diverse range of individual companies and hospitals. Despite such studies, healthcare technology investment and adoption remains fairly low in the United States. In a 2005 report, the RAND Corporation reported that just 5.5 percent of US hospitals had installed (or contracted to install) the three major clinical IT applications: computerized physician order entry (CPOE), electronic medical records (EMR), and picture archiving and communications systems (PACS). Research findings published in 2006 argue that the United States lags by as much as a dozen years behind other industrialized countries in IT adoption. The dearth of adoption is due to many factors, but significant among these is the lack of compelling evidence of the contribution of IT to improved organizational performance, or a positive return on investment (ROI).

There has been considerable research on healthcare IT adoption and benefits during the past decade, yet the results do not always add up to a compelling business case for hospital boards or business leaders. This lack of a compelling business case is particularly true for the multi-million dollar investments required to purchase and install the specialized applications that support clinical practice. Even the most notable studies on the topic—including those by institutions such as the Agency for Healthcare Research and Quality (AHRQ), the Federal Reserve Board, and the RAND Corporation—have been unable to definitively establish a causal relationship between IT investment and operational performance.

Prior research in the field is also limited by the sample of hospitals studied for the positive impacts of IT. Many studies have concentrated on institutions that are not generally considered representative of all hospitals. Moreover, the methods applied in many of the available studies had insufficient explanatory power to produce firm conclusions. For example, these considerations led the 2006 report from AHRQ (a federal agency charged with improving the quality, safety, efficiency, and effectiveness of US healthcare) to conclude that the available literature

addressing the question of healthcare IT investment and benefit is still inconclusive. (For a detailed discussion of these and other relevant studies, see Table 1, “Summary of Notable Healthcare IT Productivity Research,” on page 8.) Indeed, a recent *Health Affairs* article¹ argued a significantly contrarian position, pointing out that healthcare IT may lead to higher billings and declines in provider productivity but no change in provider-to-patient ratios, and that error reduction is inconsistent and has not been associated with reduced malpractice premiums.

Hospital executives are left to wonder: Will an investment in healthcare IT really pay off? How sizable an investment is required and how long will it take to realize a return? Will our organization realize significant quality- and cost-related benefits that can be measured? How does our organization compare to other hospitals where IT investment and its relationship to organizational performance is similar to ours? Is our existing IT infrastructure delivering what it should?

To explore these questions, PricewaterhouseCoopers and researchers at the Wharton School of the University of Pennsylvania studied US hospitals in a manner that builds upon previous work in the field of IT and business productivity. This research attempts to help fill a significant gap in available information, a gap that affects both individual hospital decisions and broad policy discussions. The current study uses econometric techniques to investigate the relationship between IT adoption and organizational performance in hospitals. Prior research is discussed in more depth later in this section.

Our research was designed to provide new insights into the relationship between healthcare IT investment and organizational performance. The study’s goals are twofold: first, to establish whether there is any empirical evidence that healthcare IT investment can be said to directly affect hospital performance; and second, to create a statistically sound benchmarking approach to model the unique contributions of IT to organizational effectiveness while taking into account the complex interplay of other factors.

The goals of the study could be described as seeking to measure the effect of IT investment on the first three “key characteristics of the 21st century health system,” as outlined in the Institute of Medicine (IOM) report *Crossing the Quality Chasm*, namely:

1. Safety
2. Effectiveness
3. Efficiency

1. J. Siderov, “It Ain’t Necessarily So: The EHR and the Unlikely Prospect of Reducing Healthcare Costs,” *Health Affairs* 25 (July/August 2006): 1,079–1,085.

Powerful, persuasive empirical research requires solid data from large, representative samples of hospitals. Our current study obtained source data for the first three IOM characteristics, but more primary research is needed for the others. As trusted data sources become available for the other attributes, we may be able to adapt our modeling methodology to explore those as well.

During the past two decades, numerous institutions have undertaken research with similar goals—mostly examining industries other than healthcare. Many of these studies used established economic theory and econometric techniques, in which researchers use mathematical formulas to model the real-world behavior of organizations. (For a more detailed discussion of economic models, see the section “Overview of Our Economic Model” on page 20.)

One approach often applied in studies of IT impact involves the development of a production function, a formula that describes the output of a production process as a mathematical function of its inputs. Prior studies using this approach have been conducted at both the industry level (entire economies or vertical markets) and organization level (individual companies) and have produced significant support for the theory that IT contributes positively to organizational performance. (See Figure 1.)

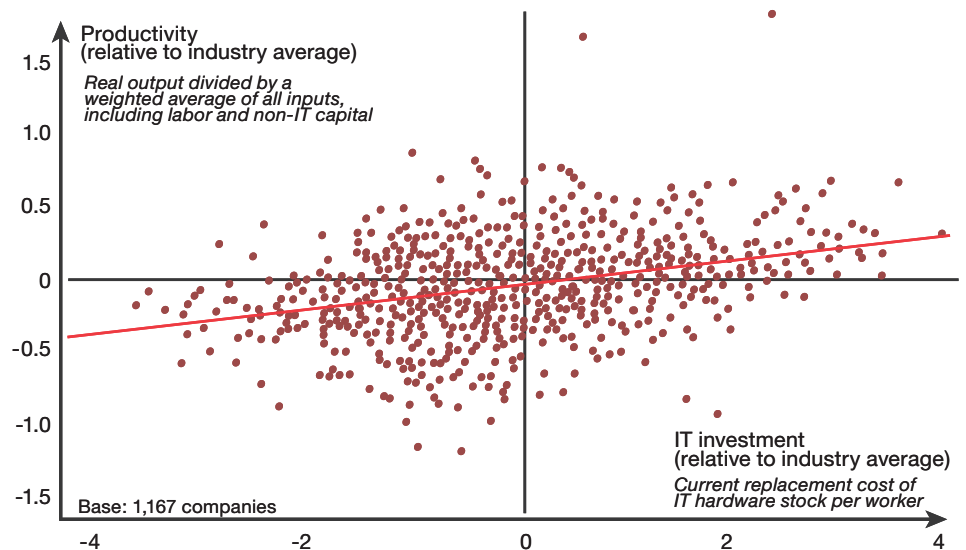
A substantial body of work in the field was produced during the past 10 years by Erik Brynjolfsson, of the MIT Sloan School of Management, and Lorin M. Hitt, at the Wharton School of the University of Pennsylvania. (Hitt also collaborated on the PricewaterhouseCoopers and Wharton School study.) A study by Brynjolfsson and Hitt, “Computing Productivity: Firm-Level Evidence,” published in 2003, focused on what it described as general IT—computer hardware such as PCs and servers. It used a production function approach (and other standard growth accounting and productivity measurement approaches) to examine the relationship between computer spending growth and productivity growth. The study used a panel data set, containing observations on multiple variables observed over multiple time periods, of more than 500 large US organiza-

tions over a seven-year period. However, the study did not include healthcare delivery organizations.

The 2003 study by Brynjolfsson and Hitt found that in the short term (over a one-year period), IT’s contribution to productivity was roughly equal to its capital cost. But over longer periods, such as five- or seven-year periods, IT’s contribution to productivity and output were as much as five times greater than its input costs. This significant difference demonstrates the importance of incorporating analysis of time-lag effects in our research. Although the 2003 study focused only on hardware, these results are consistent with the suggestion that IT investment is generally accompanied by relatively large and time-consuming organizational changes, such as those related to business process and human capital. Indeed, few commentators would now believe that reaping the full benefits of IT could be accomplished without such changes.

Research utilizing such a framework and approach has not yet been published for the healthcare industry. Doing so would provide compelling empirical evidence for IT’s positive impact on hospital performance.

Figure 1: Relationship of IT Investment to Productivity in the US Economy, Not Including Healthcare



Source: Erik Brynjolfsson and Lorin Hitt, Optimize, March 2006

Table 1: Summary of Notable Healthcare IT Productivity Research

Study	Author/institution	Purpose
<p><i>Costs and Benefits of Healthcare Information Technology: Evidence Report/Technology Assessment No. 132</i></p> <p>Also published as “Systematic Review: Impact of Health Information Technology on Quality, Efficiency, and Costs of Medical Care”</p>	<p>Southern California Evidence-based Practice Center, Santa Monica (prepared for AHRQ), April 2006</p> <p>Basit Chaudhry, M.D., Jerome Wang, M.D., et al., <i>Annals of Internal Medicine</i>, 2006</p>	<p>Evidence report regarding costs and benefits of healthcare IT systems, particularly those providing pediatric care</p>
<p>“The State and Pattern of Health Information Technology Adoption”</p>	<p>Kateryna Fonkych and Roger Taylor, RAND Corporation, 2005</p>	<p>Study clinical healthcare IT adoption patterns and levels across 3,600 US healthcare providers to guide policy development for healthcare IT adoption and investment</p>
<p><i>Measuring the Cost Impact of Hospital Information Systems: 1987–1994</i></p>	<p>Ron Borzekowski, Board of Governors of the Federal Reserve System, 2002</p>	<p>Examine effect of healthcare IT on operating costs of 3,000 US hospitals</p>
<p>“Information Technology Implementation and Efficiency in the US Hospital Sector 1997–2001: A Production Function Approach”</p>	<p>Brad R. Atkinson and Tony Cockerill, Durham University UK, 2006</p>	<p>Test whether more aggressive IT implementation yields higher efficiency among 2,700 US acute care hospitals</p>
<p><i>EMR Sophistication Correlates to Hospital Quality Data</i></p>	<p>HIMSS Analytics, 2006</p>	<p>Compare EMR adoption (based on HIMSS Analytics’ EMR Adoption Model) to care outcomes at University HealthSystem Consortium (UHC) hospitals</p>

Relevance to PwC–Wharton study	Findings	Opportunities for improvement
<ul style="list-style-type: none"> • Screened 855 studies of healthcare IT costs and benefits • Analyzed 256 in detail 	<p>Concluded that there was much encouraging evidence, but made clear the lack of compelling, generalizable economic evidence for a return on investment on healthcare IT, and identified an unmistakable need for additional study</p>	<p>The study is thorough as a review article, providing an assessment of available evidence. However, the study leaves many questions unanswered—a reflection of the evidence upon which it is based.</p>
<ul style="list-style-type: none"> • Used panel data from two of the sources used in the PwC–Wharton study • Identified different adoption patterns between for-profit and not-for-profit hospitals; not intended to provide evidence of operational or clinical impact 	<p>Concluded that one of the primary barriers to adoption was lack of business case</p>	<p>The study provided a snapshot assessment of IT adoption—not a time-series analysis. The study assessed factors associated with IT investment, rather than the effects of investment.</p>
<ul style="list-style-type: none"> • Relied on economic modeling, using cost function • Able to analyze the impact of individual healthcare IT applications on operating cost • Used time-lag approach to account for the organizational changes that accompany IT adoption 	<p>Found evidence that financial/administrative and clinical IT systems at the most automated hospitals were associated with declining costs three and five years after adoption</p>	<p>The study used a very simple IT adoption scale. Application-type impacts were not separable, and explicit cost-benefit calculations were not enabled.</p>
<ul style="list-style-type: none"> • Relied on economic modeling, using production function • Considered degrees and strategy of IT investment, segmenting hospitals in seven groups • Used time-lag approach to account for the organizational changes that accompany IT adoption 	<p>Found evidence of efficiency gains, particularly improved utilization of clinicians, for aggressive IT implementers relative to the rest of US hospitals in the study</p>	<p>The study used an imprecise and subjective measure of IT adoption. The impact of healthcare IT on quality of care was not studied.</p>
<ul style="list-style-type: none"> • Attempted to correlate levels of EMR functionality with care quality indicators 	<p>Reported no overall correlation between EMR scores and quality scores; provided (weak) evidence that hospitals at higher levels of EMR adoption had higher counts of “positive” correlations</p>	<p>The study suffered from small sample size and challenges in statistical methodology.</p>

Foundational Healthcare IT Research

Although broad-based and econometrically sound evidence of IT's impact on hospitals is quite limited today, several studies suggest an effect might be detectable. The following summaries highlight five recent healthcare studies that provide a backdrop for the current analysis. For an overview of the relevance of each study to our work, refer to Table 1 on page 8.

Costs and Benefits of Healthcare Information Technology: Evidence Report/Technology Assessment.

The AHRQ study, conducted by the Southern California Evidence-based Practice Center, Santa Monica, was published in 2006 and included a thorough review of the available literature on the topic of the costs and benefits of healthcare IT. The study surveyed more than 850 papers before reporting: "We identified no study or collection of studies, outside of those from a handful of HIT (healthcare information technology) leaders, that would allow a reader to make a determination about the generalizable knowledge of the study's reported benefit. Beside these studies from HIT leaders, no other research assessed HIT systems that had comprehensive functionality and included data on costs, relevant information on organizational context and process change, and data on implementation. A small body of literature supports a role for HIT in improving the quality of pediatric care. Insufficient data were available on the costs or cost-effectiveness of implementing such systems." Although optimistic in its overall assessment, the review made clear the lack of compelling economic evidence for a return on investment of healthcare IT and identified an unmistakable need for additional empirical research. The AHRQ findings may have been particularly surprising for readers familiar with the case studies that software vendors promulgate. The answer may lie in the reminder that multiple case studies do not necessarily sum to form conclusive evidence.

The State and Pattern of Health Information Technology Adoption.

A 2005 RAND study by Kateryna Fonkych and Roger Taylor examined clinical healthcare IT (EMR, CPOE, and radiology PACS) adoption patterns and levels across US healthcare providers. The stated purpose of the study was to guide policy development for healthcare IT adoption and investment. However, although the study explored the relationship between clinical healthcare IT adoption levels and several facets of hospital performance, its design (using observational data from only a single year) does not support conclusions about IT investment's causal effects.

The RAND study used a data set of approximately 3,600 hospitals in the United States. The cross-sectional

study relied on IT adoption data from the 2004 HIMSS Analytics™ database (derived from Dorenfest IHDS+ Database™) and merged this data with demographic data from the American Hospital Association (AHA) Annual Survey Database.

The RAND study found that clinical IT adoption was significantly lower among for-profit hospitals than not-for-profit hospitals. It also found that hospital and health system characteristics as well as market factors affected adoption. According to the study's conclusion, these differences suggest that the largest barriers to clinical healthcare IT adoption may not be access to capital but other factors, such as the business case that can be made for its implementation. Although valuable as a characterization of the state of IT adoption in US hospitals, the study did not provide compelling evidence of economic or quality returns associated with such investments. It focused on explaining the level of IT adoption in different segments of the US healthcare system rather than looking for the economic effects of such investments.

Measuring the Cost Impact of Hospital Information Systems: 1987–1994.

Another highly relevant study to our current research was conducted by the Federal Reserve Board economist Ron Borzekowski in 2002. The study examined the effect of healthcare IT on hospital operating costs using an eight-year panel data set to analyze approximately 3,000 US hospitals. This approach enabled Borzekowski to analyze the impact of individual healthcare IT applications on hospital costs. It found that financial/administrative and clinical IT systems at the most automated hospitals were associated with declining costs three and five years after adoption.

Borzekowski used simplifying assumptions to model IT adoption, adding up the number of applications that a hospital claims to have. This method of measuring IT investment does not distinguish between different applications, nor does it factor in the high variability of costs associated with investments in different applications. Without IT cost data, estimating cost-benefit ratios is impossible.

Information Technology Implementation and Efficiency in the US Hospital Sector 1997–2001: A Production Function Approach.

Published in 2006 and conducted by Brad R. Atkinson and Tony Cockerill of Durham University UK, the study looked at whether hospitals that were more aggressive in implementing IT would realize higher efficiency than those hospitals that were less aggressive or did not implement IT at all. The study used economic modeling and a panel data set for some 2,700 US acute care hospitals. An important element of the study was its segmentation of hospitals into seven

groups based upon their IT investment strategy using subjective ratings, from consistently aggressive implementers to non- and weak implementers. Aggressive implementers improved their efficiency more than other hospitals in the study; these efficiency gains came primarily from improved utilization of clinicians. The study also found a positive association between efficiency and the market penetration of managed care, suggesting that IT investment strategy can be linked to both cost reduction and revenue enhancement.

EMR Sophistication Correlates to Hospital Quality Data. In 2006, HIMSS Analytics reported a study that examined statistical correlations between the level of EMR implemented and AHRQ care quality indicator scores at 107 University HealthSystem Consortium (UHC) hospitals. For each of 63 AHRQ quality indicators, correlation coefficients were calculated between hospitals' quality scores and their EMR implementation scores (based on the HIMSS Analytics EMR Adoption Model). The study reported that although there was "little or no correlation between EMR scores and improved care for the entire aggregate of UHC hospitals," there was some indication that hospitals with higher EMR scores (for example, Stage 4—using such advanced features as CPOE and clinical decision support—and above) had a higher number of quality indicators with a "strong" positive correlation to EMR scores. This study reported only the number of "strong" or "slight positive" correlations for each indicator without indicating levels of statistical significance, but the study's conclusion that "there is a fairly dramatic leap in the impact of hospital EMRs once an institution has achieved Stage 4 status" is of interest.

In summary, previous research outside the healthcare field on the impact of IT on organizational performance has provided a growing and compelling argument for a positive contribution from IT. This previous research also shows that the impact grows over a period of years after the original IT investment. Peer-reviewed, published academic research has validated that econometric models of production functions are some of the best ways to infer causality between IT investment and higher organizational performance. Finally, this review of research has established that the hospital sector has yet to be studied in this rigorous and empirical way.

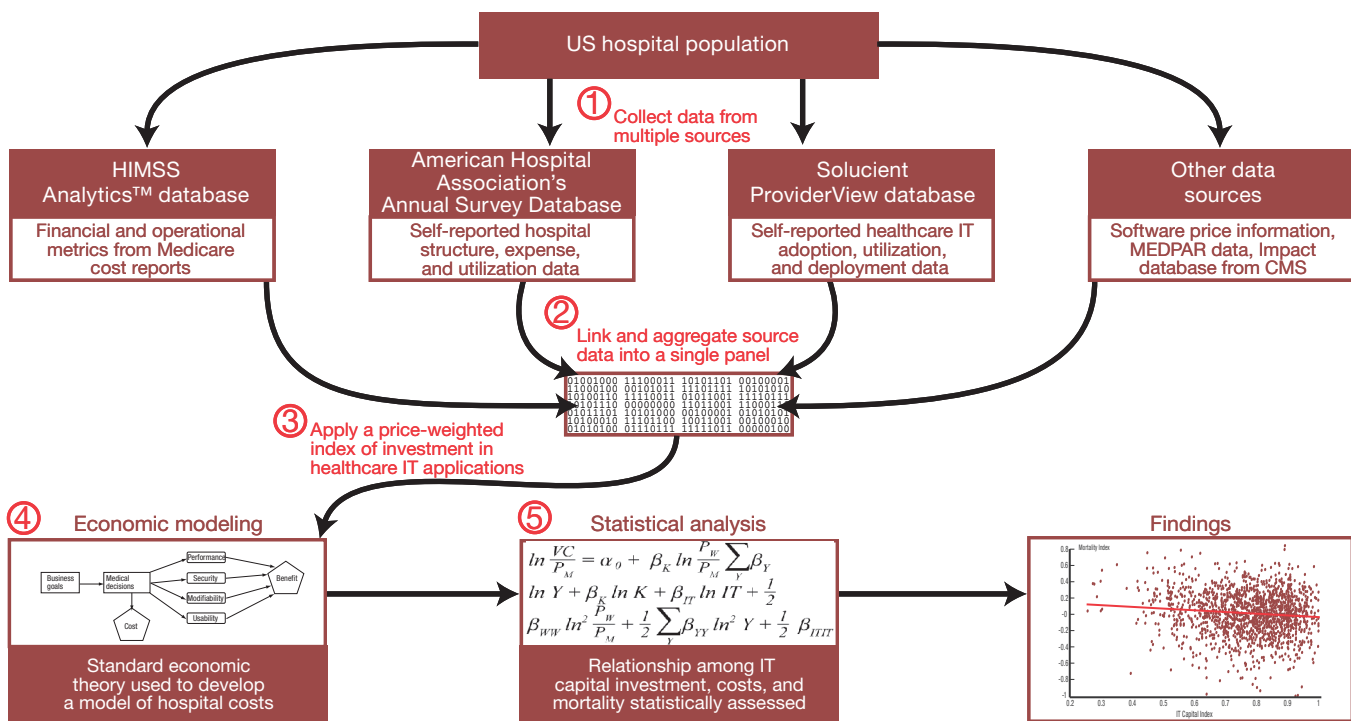
Study Design

The goal of the PricewaterhouseCoopers and Wharton School study was to seek evidence that investment in healthcare IT has an effect on organizational performance. To this end, we created a panel of data derived from several sources that cover the majority of US hospitals. We then assessed the relationship between IT investment and two measures of hospital performance (operating expenses per bed and mortality rates) by applying advanced statistical and econometric techniques. Figure 2 outlines the overall approach of the study.

US hospitals. We also merged and utilized data from the Centers for Medicare and Medicaid Services Prospective Payment System Impact files. The study explored data from 1999 to 2004.

In assembling a large research data set of this kind, a number of challenges must be overcome. These include the intrinsic complexity of the healthcare industry, which can lead to inaccurate data. Even a simple term, such as number of admissions, may have different meanings in different hospitals: Does it include day cases? What about

Figure 2: Overview of Study Approach



Data Sources

We began our study by combining data from several sources, which we linked by hospital identifier data. The study required three types of data: hospital services and facilities utilization data, healthcare IT investment data, and hospital cost data. Data sources included the Solucient ProviderView database and the American Hospital Association's Annual Survey Database, which contain considerable data describing annual cost, operational, and capital investment characteristics for more than 6,000 US hospitals. Healthcare IT adoption data was drawn from the HIMSS Analytics™ database (derived from Dorenfest IHDS+ Database™), which contains annual hospital-level information on healthcare IT adoption for

emergency room overnight stays? Additional challenges include the complex inter-correlations between important variables in the data. For example, the study seeks evidence of the impact of IT on hospital efficiency, yet efficiency itself may be closely correlated with other factors, such as for-profit or not-for-profit status, teaching status, or simply size. The effects of IT—especially among more complex, enterprisewide applications—are also unlikely to manifest themselves during the year of implementation.

Differences among geographies may influence the degree to which a sample is representative of all hospitals. These differences could be jurisdictional, causing variation in mandated patient-nurse ratios, for example.

Differences also could include variations in the proportions of for-profit and not-for-profit hospitals, various wage and other expense factors, as well as other population characteristics.

A further challenge is that available data does not always include all the information needed to fully develop an accurate economic model or assess ROI. For example, although the HIMSS Analytics database is the best available source of information about which hospitals have which IT applications, it nevertheless creates some difficulties for the researcher. The data structures have changed subtly over time (for the better, but changes nevertheless), requiring careful mapping to ensure full use of the data. Moreover, the data is derived from a self-reported survey by hospitals, and there is anecdotal evidence that not all hospitals report in a precisely consistent manner. Finally, the data describes the applications an organization has and not necessarily how fully the applications are used.

Such challenges are usually unavoidable in any large-scale econometric study, and researchers generally assume that the data describes what it purports to describe and that any errors will be randomly and evenly distributed throughout the data. These assumptions are key; if the data is inaccurate but errors in measurement are random, then the statistical power of the analysis is reduced. In this study, any bias under those circumstances would be toward failing to find a relationship between IT and organizational performance when such a relationship does, in fact, exist. In other words, our findings of a relationship are likely to be conservative and biased in the direction of not finding an effect.²

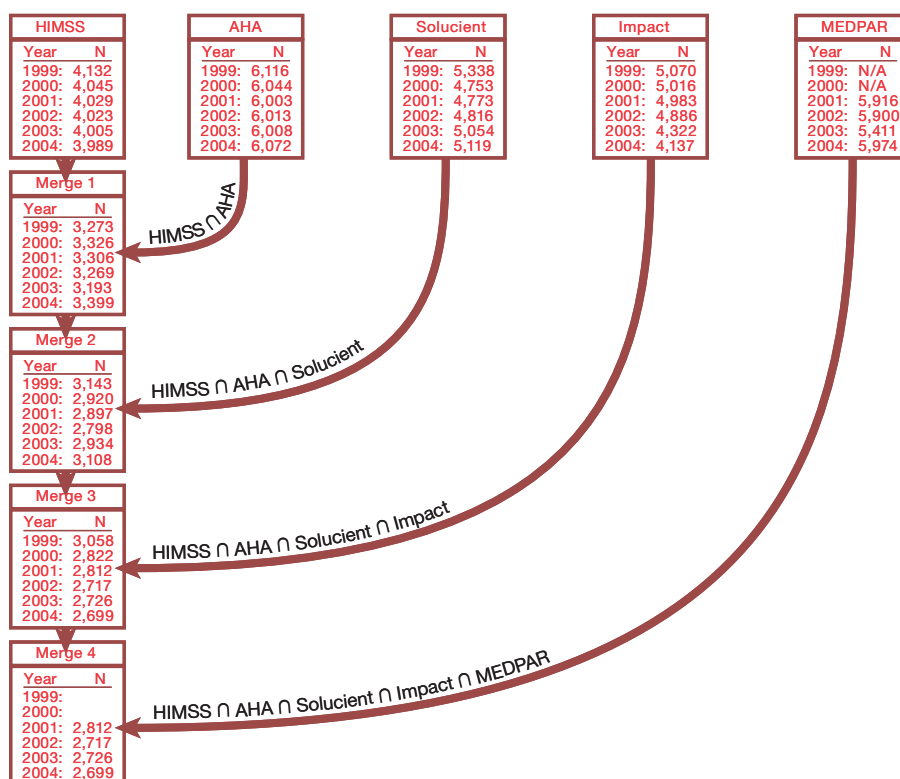
Panel Data Set

To prepare the data for statistical analysis, we merged the data from the key sources into one panel data set (with data grouped by year, 1999 through 2004). Where we could not match a hospital across data sets for a given year, missing values for any year were estimated automatically by the statistical

software package,³ based on values from previous and subsequent years. (See Figure 3 for more detail of the data merge process.) In addition, we excluded some hospitals if they were missing data on key variables of interest. For these reasons, merging the data reduced the working sample size from the more than 6,000 hospitals in the full census of US hospitals to the final sample of approximately 2,800 US hospitals in each year of the data panel. Finally, we deliberately excluded a number of different hospital types and outliers⁴ to promote comparability of the sample. These further exclusions reduced the panel to just fewer than 2,000 hospitals.

As Figure 3 shows, the result of merge 3 was a thorough six-year data set for all hospitals in the final sample and was the data panel used for our examination of IT investment and hospital performance. The result of merge 4 (the merging of Medicare Provider Analysis and Review [MEDPAR] data, resulting in a four-year panel) was used for our examination of IT investment and hospital mortality.

Figure 3: Details of Data Merges and Panel Sizes by Year



2. For more discussion on the assumptions that our model makes regarding the random distribution of error, see *Econometric Analysis* by W. H. Greene (New York: Macmillan, 1993).

3. The statistical program we use in this research is STATA.

4. Hospital types excluded were rural hospitals, psychiatric hospitals, children's hospitals, government hospitals, Kaiser system hospitals, long-term care hospitals, hospices, and hospitals in Alaska, Hawaii, or Puerto Rico. For our analysis, we also excluded as outliers hospitals whose operating expenses were three standard deviations above or below the mean.

Table 2 presents descriptive statistics on the hospitals included in the sample and compares them with the more than 6,000 hospitals in the full census of US hospitals. Smaller hospitals that have fewer than 100 beds are somewhat underrepresented in the analysis.⁵ On the other hand, teaching hospitals and hospitals affiliated with a medical school are overrepresented in the sample. The geographic distribution of sampled hospitals, however, is fairly representative of the distribution of hospitals by population. Although there are some discrepancies between the population and our sample, they are not so severe as to undermine the applicability of the results. Our panel is generally representative of the acute care hospitals in the United States, particularly the hospitals that usually experience pressure to invest in IT.

Measuring IT Investment

Before we describe how we measured IT investment for the current study, it is important to clarify the terminology used to refer to acquisition and use of IT in the healthcare industry:

IT adoption— Sometimes used to mean the act of an organization adopting an information system, or acquiring the rights to use an information system. IT adoption also refers to actual system use by the staff of an organization that has rights to the system. Generally, in this paper we use the term IT adoption in the former sense, referring to acquisition of systems by organizations. The research here does not distinguish between different levels of end-user system utilization in two hospitals that have otherwise identical systems. If the latter sense—end-user adoption rates within an institution—is implied, the paper will make this intent clear.

5. This underrepresentation is generally a result of the survey strategy employed by HIMSS Analytics (and previously by Dorenfest & Associates); that is, IT capital data is missing for many hospitals that have fewer than 100 beds.

Table 2: Descriptive Statistics for the Study Sample and Population of US Hospitals

	Hospital sample ¹		Hospital population ²	
	1,978 hospitals		6,072 hospitals	
	Number	%	Number	%
Hospital beds				
Fewer than 50 beds	133	6.7	1,690	27.80
50 to 99 beds	189	9.6	1,341	22.10
100 to 199 beds	582	29.4	1,390	22.90
200 to 299 beds	444	22.5	728	12.00
300 to 399 beds	276	14.0	396	6.50
400 to 499 beds	149	7.5	210	3.50
More than 500 beds	205	10.4	317	5.20
Geographic region				
Eastern hospitals	462	23.4	951	15.70
Western hospitals	373	18.9	713	11.70
Southern hospitals	716	36.2	2,637	43.40
Midwestern hospitals	427	21.6	1,771	29.20
Ownership status				
For-profit hospitals	421	21.3	1,206	19.90
Not-for-profit hospitals	1,542	78.0	3,181	52.40
Local government hospitals	15	0.8	1,443	23.80
Federal government hospitals	0	0.0	242	4.00
System membership				
Nonsystem hospitals	594	30.0	2,820	46.40
System hospitals	1,384	70.0	3,252	53.60

¹ Hospitals are included in this breakdown if they appear at any point in our panel data set (1999 to 2004). Although these figures rarely change, we used the most recent data available to generate these statistics.

² Data on the population of US hospitals comes from the 2004 American Hospital Association (AHA) Database.

IT investment— The general level of organizational financial expenditure associated with IT, which includes software, hardware, services, staffing, and other costs. All these expenditures—both capital expenses and continuing IT operating expenses—are part of the overall investment in IT.

IT capital— The distinction between the level of capital investment (in the economic sense, rather than necessarily in the accounting sense, which may be different) in all

information systems. These systems usually include hardware, software, networking infrastructure, and other capital equipment associated with the provision of information services. Such acquisitions are not always financed through direct capital acquisition, but instead may be rented or outsourced and therefore treated as an operating expense, or perhaps financed in other ways. From an economic modeling point of view, the payment method is less important, although it would be strictly more accurate to acknowledge that immediate and full expensing of capital acquisitions is less expensive in the long term.

IT Capital Index—The construct we developed to measure the level of IT investment in an organization. This construct is explained in the following discussion.

Our study required the development of a meaningful measure of IT investment. We considered several different approaches used in previous studies. (See Table 3.) However, given the shortcomings of each, we determined it was necessary to define a more precise measure of IT investment: an index value based on an approximation of capital invested in IT software.

ing information from a number of illustrative pricing proposals from several software vendors, redacted to protect commercially sensitive information, such as specific vendor or customer. This approach enabled us to ascertain an approximate software investment value for each hospital for each year for which we had data in the panel.

To quantify our IT Capital Index, we used a weighted application count model: we added the prices paid (assuming that the prices in our standard price list were representative of actual prices paid) for those applications (Table 9 on page 18 lists the applications) and then expressed each result as a proportion of the total amount that a hospital could possibly pay had it acquired all the available applications. This proportion was then expressed as a value between 0 and 1. For example, if a hospital’s purchased software applications summed to \$10 million out of a theoretically possible \$20 million, the hospital’s score would have been 0.5 on our IT Capital Index scale.

Although the values assigned to specific hospitals are derived solely from consideration of their software profiles, we have assumed that the ratio of software to hardware

Table 3: Prior Approaches to Measuring IT Investment

Name	Approach	Disadvantages
Application count	Tallies the number of healthcare IT applications implemented at an organization	This simplistic approach treats all applications equally and does not take into account the varying degrees of organizational and capital costs required for implementation.
Spetz-Saiden index	Akin to application count, but healthcare IT applications that are more rarely implemented receive a higher weighting	This weighted approach equates rarity with high value, but in some cases a healthcare IT application is not widely implemented because it has not been found effective.
Functional sequence scale	A scale developed on the basis of the level of IT adoption that an organization has attained, which combines typical historical implementation paths with subjective assessments of how advanced an application infrastructure is	Not all institutions follow equivalent implementation paths. The dollar value of the level of functional sequence attainment may be difficult to assess.

To assess how much IT an organization had, we adopted an approach that recognized that not all applications have equivalent scope, scale, cost, or complexity. Instead of simply adding up how many applications a hospital had, we began by making the assumption that the price of an application was a reasonable proxy for the factors of scope, scale, cost, or complexity—that is, we assumed that applications that are more complex, or that affect more users, tend to be more expensive. We obtained pric-

ing information from a number of illustrative pricing proposals from several software vendors, redacted to protect commercially sensitive information, such as specific vendor or customer. This approach enabled us to ascertain an approximate software investment value for each hospital for each year for which we had data in the panel.

Figure 4: Distribution of For-Profit and Not-for-Profit Institutions in IT Capital Index

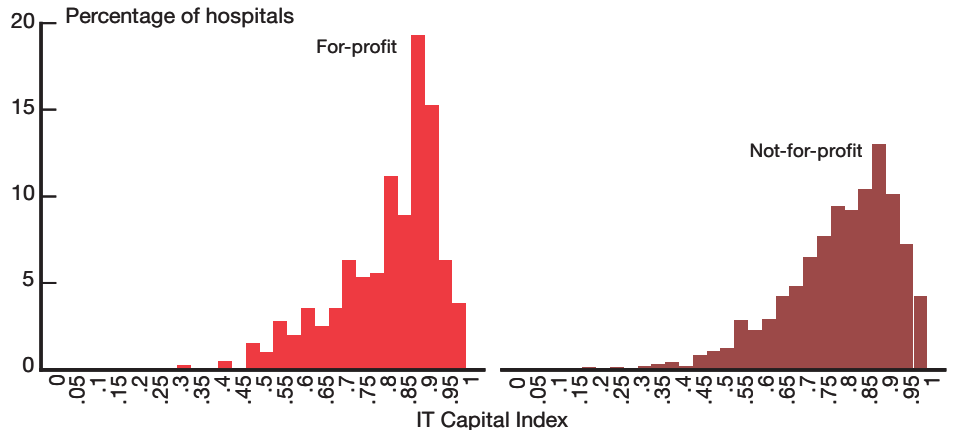


Table 4: Illustrative Software Expenditures by Quintile, 2004

Quintile	For-profit institutions			Not-for-profit institutions		
	Observations	Average no. of beds	Maximum IT cost*	Observations	Average no. of beds	Maximum IT cost*
First	81	160	11.8	302	206	11.4
Second	92	190	13.6	302	288	13.0
Third	64	175	14.5	304	293	14.2
Fourth	101	213	15.2	300	302	15.1
Fifth	56	241	16.2	302	340	16.7

*Maximum illustrative IT expenditure value within the quintile, in millions of dollars.

Table 5: Distribution of IT Capital Index Scores by Number of Beds

Number of beds	Observations	Mean	Std. Dev.	Min.	Max.
Fewer than 50 beds	87	0.717	0.179	0.162	0.978
50 to 99 beds	188	0.751	0.144	0.297	0.993
100 to 199 beds	575	0.763	0.140	0.193	0.993
200 to 299 beds	441	0.804	0.115	0.361	0.993
300 to 399 beds	275	0.809	0.121	0.378	0.993
400 to 499 beds	148	0.832	0.105	0.491	0.993
More than 500 beds	205	0.827	0.101	0.510	0.993

Table 6: Distribution of IT Capital Index Scores by Region and by System

Region or system	Observations	Mean	Std. Dev.	Min.	Max.
Eastern	461	0.771	0.139	0.288	0.982
Western	326	0.785	0.131	0.297	0.993
Southern	710	0.805	0.126	0.162	0.986
Midwestern	422	0.779	0.132	0.193	0.993
Nonsystem	577	0.763	0.140	0.193	0.986
System	1,342	0.799	0.127	0.162	0.993

In summary, our metric of IT investment, which we have termed the IT Capital Index, is a relative score based on the reported acquisition of healthcare applications. This metric of IT investment reflects actual expenditures undertaken and enables the detection of potentially different contributions of each application to hospital performance. Although imperfect, the IT Capital Index represents a quantitative and usable indicator of software being used in US hospitals.

Figure 4 and Tables 4 through 9 provide statistics that characterize IT Capital Index distributions for our data panel.

For purposes of illustration, a value of 0.8 on the IT Capital Index axis in Figure 4 corresponds to a software capital expenditure of approximately \$13 million for a medium-sized hospital. (This amount does not include hardware, networking, or implementation costs.) It is important to note that the IT Capital Index is a relative, not absolute, scale and different facilities (according to size, complexity, commercial arrangements, and so forth) may have spent significantly different amounts to acquire and use a particular configuration of software.⁶ Table 4 shows hospital expenditures on software and breaks the sample into quintiles (five groups each representing 20 percent of the sample).

As Table 7 shows, we observed higher⁷ average IT Capital Index scores for for-profit hospitals than for not-for-profit hospitals in our overall sample. To understand how our results contrasted with the earlier RAND study, which found that IT adoption for clinical systems was lower among for-profit hospitals than not-for-profit hospitals, we further examined IT Capital Index scores by application type as shown in Table 8. To do this, we applied the same technique as for the overall IT Capital Index scoring, but separately for clinical applications and administrative applications. This means, for example, that a hospital with every possible clinical application in the database will have an IT Capital Index (clinical) score of 1.0, while a hospital with no clinical applications will have an IT Capital Index (clinical) score of 0. This breakdown shows that for administrative applications (as defined in Table 9), for-profit hospitals had higher average IT Capital Index scores than not-for-profit hospitals. For clinical applications, not-for-profit hospitals had higher average IT Capital Index values than for-profit hospitals (consistent with the RAND findings); however, the difference was not statistically significant.⁸ The higher average IT Capital Index scores for for-profit hospitals (compared with not-for-profit hospitals) may be somewhat surprising, and we believe that two factors may provide explanation. First, for-profit hospitals have a somewhat higher level of investment in administrative

Table 7: Distribution of IT Capital Index Scores by Hospital Type

Hospital type	Observations	Mean	Std. Dev.	Min.	Max.
For-profit	394	0.801	0.124	0.297	0.964
Not-for-profit	1,510	0.786	0.133	0.162	0.993
Local government	15	0.680	0.147	0.442	0.933
Federal government	0	N/A	N/A	N/A	N/A

Table 8: Distribution of IT Capital Index Scores by Application Type

Application type	For-profit		Not-for-profit	
	Mean	Median	Mean	Median
Total	0.801	0.840	0.786	0.814
Administrative	0.858	0.897	0.821	0.846
Clinical	0.737	0.809	0.747	0.803

6. At the lower and upper ends of the IT Capital Index scale, the scope of information systems in place tends to be very similar, reflecting the characteristic implementation paths taken by adopters of healthcare IT. At midrange points, there are more variations in the manner in which hospitals may obtain a given score, and as such there is more heterogeneity in IT infrastructures implicitly described by the IT Capital Index.

7. Differences statistically significant at 0.05 level or higher, unless otherwise stated.

8. It is also important to note that our separation of clinical and administrative applications differed somewhat from that used in the RAND study, and that our IT Capital Index scoring was price-adjusted.

Table 9: Healthcare IT Applications Breakdown

Applications by category	Hospital sample	
	Number	Percentage
Administrative applications		
Base administration and financial		
Accounts payable	1,972	99.7
Benefits administration	1,913	96.7
Credit/collections	1,872	94.6
Electronic claims	1,946	98.4
Eligibility	740	37.4
General ledger	1,966	99.4
Managed care contract management	1,406	71.1
Materials management	1,954	98.8
Nurse staffing	1,510	76.3
Patient billing	1,978	100.0
Patient registration	1,978	100.0
Payroll	1,970	99.6
Personnel administration	1,937	97.9
Premium billing	114	5.8
Time and attendance	1,715	86.7
Financial decision support		
Case mix analysis	1,872	94.6
Clinical decision support (retrospective)	1,295	65.5
Cost accounting	1,683	85.1
Executive information system	1,340	67.7
Flexible budgeting	1,750	88.5
Outcomes and quality management	1,307	66.1
Medical records		
Abstracting	1,958	99.0
Chart deficiency	1,918	97.0
Chart tracking/locator	1,883	95.2
Encoder	1,947	98.4
Master patient index	1,971	99.6
Medical record imaging	741	37.5
Transcription (includes dictation)	1,838	92.9
Clinical applications		
Ancillary department		
Laboratory	1,947	98.4
Radiology	1,872	94.6
PACS (includes radiology PACS and cardiology PACS)	917	46.4
Clinical department		
Cardiology	599	30.3
Emergency department (formerly emergency room)	1,069	54.0
Intensive care (formerly critical care)	623	31.5
Pharmacy (includes pharmacy dispensing)	1,962	99.2
Surgery	1,714	86.7
Enterprise clinical		
Clinical data repository (includes computerized patient record)	1,543	78.0
Clinical documentation (formerly nurse chart/care plan)	1,442	72.9
Order communication/results	1,898	96.0
Point of care (formerly med/surg bedside term)	875	44.2

and financial applications. Second, the greater maturity of the financial and administrative systems markets may have produced a higher degree of disaggregation of these applications, leading to higher apparent scores on our index. Fuller understanding of observed differences in IT Capital Index scores between the for-profit and not-for-profit sectors is an area of potential continuing research.

In addition to assessing the approximate cost of the software applications, we also grouped the applications into broad categories that would permit us to divide aggregate IT expenditures into subcomponents and determine whether any specific type of application (such as administrative or clinical) yielded greater efficiency gains than any other. These categories are shown in Table 9.

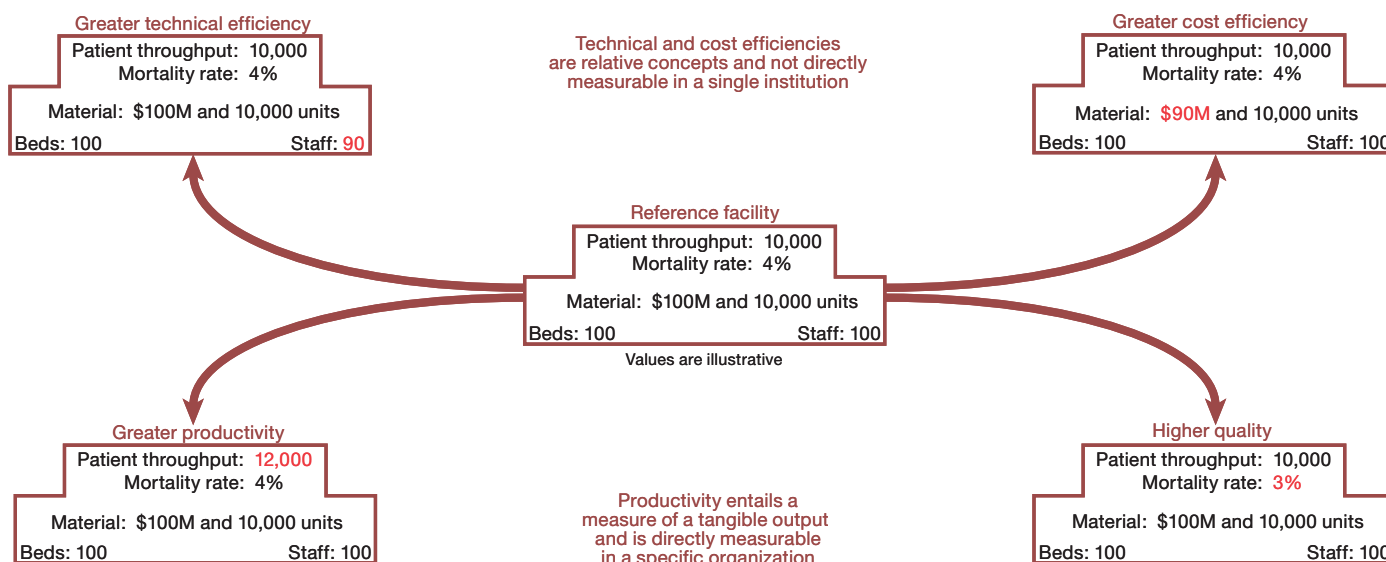
Table 9 shows all the applications for which ownership information was available for US hospitals in our panel. Table 9 also shows 2004 panel data for each application, both the number and percentage of hospitals reporting acquisition. The application categories in Table 9 reflect some changes in naming and grouping that occurred in the HIMSS Analytics database between 1999 and 2004.⁹

In addition, a small number of missing panel data values were imputed backwards using data from adjacent years.¹⁰

Measuring Hospital Performance

Several facets of organizational performance are closely connected to one another and should be semantically disentangled before we proceed. Use of the sole term efficiency is often ambiguous because it has different forms: technical efficiency and cost efficiency. Technical efficiency measures the rate at which an organization uses inputs to produce outputs (for example, the number of full-time equivalents [FTEs] and beds that a hospital “uses” to “produce” a certain number of patient days). As Figure 5 illustrates, technical efficiency is closely related to the term productivity and sometimes the terms are used interchangeably. Cost efficiency, on the other hand, takes into account the costs of these inputs; it ultimately describes how much an organization spends on its inputs to produce a given level of output. As indicated in Figure 5, cost-efficient behavior involves minimizing costs for a given level of output or maximizing production for a given cost. In this study, we chose to focus our initial investigations on hospital cost efficiency.

Figure 5: The Different Facets of Efficiency



Efficiency is a widely—and sometimes imprecisely—used term. The different facets of efficiency, and their technical definitions, are illustrated in this diagram by comparing four different institutions with a central reference facility.

9. Specifically: Computerized patient record first appeared as a category in 2002 and henceforth was counted as clinical data repository; clinical documentation was labeled nurse chart/care plan prior to 2002; emergency department was labeled emergency room prior to 2002; intensive care was labeled critical care prior to 2002; PACS (which included only radiology PACS from 1999 to 2003) now includes radiology PACS and cardiology PACS; pharmacy dispensing (discontinued after 2003) was counted in the pharmacy category; point of care was labeled med/surg bedside term prior to 2002; and dictation first appeared in 2002 and was counted in the transcription category.

10. Specifically: Cardiology was imputed backward from 2000 to 1999; that is, we assumed the (missing) 1999 configuration was identical to that available for 2000. In the uncommon instance where a single hospital did not have data for 2000, we imputed backward from the next year, 2001. Emergency department was similarly imputed backward from 2000 to 1999.

Overview of Our Economic Model

When studies that link healthcare IT and hospital performance are based on an economic model, they have a greater impact because they help disentangle the many intertwined factors of hospital performance. Studies based on an economic model create more statistical power for detecting real relationships between variables, and they enhance the ability to draw conclusions about the direction of relationships. It is simply not enough for researchers to explore the degree to which one variable (in our case, IT investment) is correlated with other variables.¹¹ For example, if researchers wanted to determine the relationship between education and financial well-being, they could look for correlations between the number of years of education and an individual checking account balance. This approach is flawed, however: it is easy to imagine simply taking a loan and depositing the money in a checking account—an act that increases the checking account balance but has no (or even a negative) effect on net worth.

In healthcare, the exploration of simple correlations between IT investment and any single measure of hospital performance may entail similar difficulties. For example, perhaps IT investment enables a significantly greater number of patients to be seen—but at a higher cost per case. Or perhaps IT can reduce the cost per case—but only in association with a substantial decline in quality of care.¹² Without consideration of the relationships among the key factors that define hospital performance, it is more difficult to draw meaningful conclusions from correlations.

Our research therefore required the development of an economic model of hospital operations that enabled us to explore different aspects of the hospital's activities from different points of view. For example, we needed to examine operating expenses while taking account of other measures, such as size of facility, amount of output (number of patients treated, for example), and other factors.

Our economic model interrelates hospital capital infrastructure costs, operating expenses, outputs, material costs, labor costs, IT investment, and other factors. We used standard economic theory and statistical techniques to develop a model of hospital costs (a cost function, rather than a production function as used in some other studies). We measured overall hospital costs in absolute

dollars. However, because larger hospitals inevitably have higher expenses, we used operating expenses divided by number of beds as an approximately normalized measure of operating expenses, instead of using total operating expenses. The calculations also accounted for variation in case mix, teaching status, scope of services offered, patient volume, and other factors. In its elementary form, the mathematical representation was as follows:

$$\text{costs} = f(\text{labor costs, material costs, capital, outputs, IT investment, hospital characteristics})$$

where:

- Labor costs are based on FTEs and (adjusted) wages
- Material costs are based on medications and supplies charged
- Capital is based on number of beds (revenue adjusted)
- Output is based on patient volume (adjusted patient days)
- IT investment is based on our IT Capital Index score
- Hospital characteristics include ownership status, teaching status, case mix, scope of services, and so forth

However, this generic formula does not yet specify how the variables (labor costs, material costs, capital, outputs, and IT investment) are interrelated. To create a precise model of hospital operations, we used established economic techniques to build a more comprehensive model—a mathematical formula—that accurately predicts the real relationships found in the study data. Our model describes the relationships that inputs and their prices have with outputs and resulting variable costs (operating expenses). We used our economic model expressed in mathematical formulas (such as a translog cost function) in our advanced regression analyses to estimate coefficients for our equations that yield the best fit to our panel data. The resultant curves characterize the relationships between costs (expenses per bed) and IT investment while controlling for all other pertinent factors. (For a detailed discussion of our economic model, see Appendix: Economic Model on page 38.)

Two observations on the mathematical form of our model are pertinent. First, in formalizing our economic model, we were careful to ensure that no variables appeared on both sides of our equations. In economics, regressing a variable on some form of itself produces a statistical problem called “multicollinearity” and can frequently yield a

11. Arguments for causality are strengthened by a priori reasons to believe that causality might occur on the basis of previous research, by multivariate statistical treatments that explicitly control for other causal factors, and by time-series data that enhances the ability to infer directionality and hence causality where strong statistical relationships are uncovered.

12. We are not suggesting that these are actual consequences that will be found; they are merely illustrations of potential interpretative problems with simple correlation studies.

spurious correlation.¹³ Second, economic theory supports various models of how businesses produce goods and/or services, and some models entail assumptions that can be difficult to sustain. From a statistical standpoint, stricter assumptions tend to constrain the variables and therefore produce higher levels of statistical significance. The model we developed requires few such assumptions, and for this reason is more conservative than other techniques. Although our study design may fail to detect real relationships in the data (by not achieving traditional levels of statistical significance), we feel this possibility is preferable to making unrealistic assumptions. Case-controlled studies in the future may provide additional insights into the results.

There are two main reasons for confidence in the model. One, this model is based on well-accepted economic theory that academic institutions and leading economic theoreticians have used for modeling economic activity. The theoretical underpinnings have been widely accepted since they were initially developed in the 1970s. Two, the model (in the form in which it may be used to calculate hospital costs—or operating expenses—from other variables) accurately predicts actual hospital costs. The model we developed accounted for more than 90 percent of the variation in costs (operating expenses) per bed when tested against the actual hospital data. These facts provide reassurance that the model is an effective descriptor of hospital behavior.

The model can be used to illustrate the relationships found among the variables in the model. We used several statistical techniques to estimate the model described in this study. Our research uses a technique known as seemingly unrelated regression (SUR), which is a commonly used method in econometric work of this nature. This technique enables multiple mathematical relationships that describe the same system to be taken into account simultaneously in a regression analysis.

Specifically, our model involves two equations: the first estimates operating expense per bed as a function of costs and capital, and the second estimates the proportion of operating expense per bed that is devoted to labor/material costs. SUR allows us to estimate both equations simultaneously. As a result, we can specify productive inputs that are quasi-fixed¹⁴ (capital and IT capital) and inputs that are variable and can be adjusted more rapidly (materials and labor). In general terms, the SUR technique increases the overall effectiveness of the analysis by allowing researchers to better take into account multiple economic relationships within the system under study.

Similar estimation techniques include stochastic frontier analysis (SFA) and data envelopment analysis (DEA), both of which are also commonly used in modern statistical and econometric analysis. Although our preliminary analysis emerges from SUR estimation, we also applied SFA techniques to the data, and the results were not substantially different from those presented here. For further details on statistical methods, see the Bibliography on page 42.

Potential Conceptual Models of IT Impact

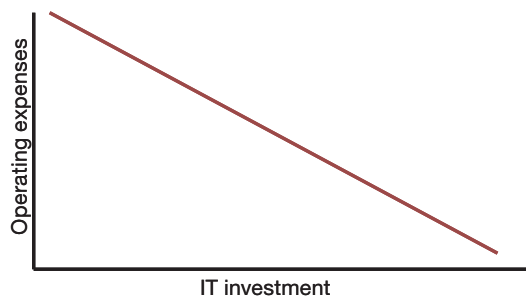
We approached our study with a simple hypothesis in mind: Healthcare IT investment leads to organizational benefits in hospitals. If healthcare IT investment does lead to performance gains, what would we expect to find? If our hypothesis is proven correct, we can begin predicting scenarios that depict the relationship between IT investment and hospital operating expenses. We can then use these hypothetical scenarios to better understand our empirically derived models. An ideal finding would be that an increase in IT investment produces an immediate and continuous reduction in hospital operating expenses and has no negative effects on any other significant aspect of the hospital's activities.

13. It would be as if we tried to predict an individual's body mass index (BMI) by regressing the value on weight and other unrelated variables. While there is not a 1:1 correlation between weight and BMI, they are directly related by a mathematical formula, and for that reason the regression would indicate a much higher predictive ability than warranted.

14. Quasi-fixed is used because, although IT has many characteristics of a variable cost (operating expense) factor, the time scale over which IT infrastructure can reasonably be changed in a hospital gives IT many of the characteristics of a fixed cost.

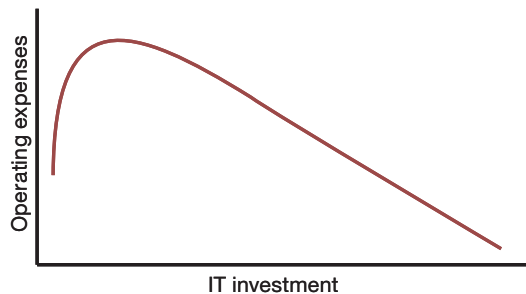
In this case, we would expect to see a graph as shown in Figure 6. However, this result is unlikely to be realistic for several reasons. First, IT investment is not continuous. For example, a hospital with practically no IT that wishes to implement a modern information systems infrastructure must undertake a number of preliminary activities, such as acquiring an IT staff, devoting facilities to the systems, and installing a network through the hospital. Thus, significant startup costs are involved in beginning to move along the IT investment axis.

Figure 6: Idealized Return-on-Investment Scenario



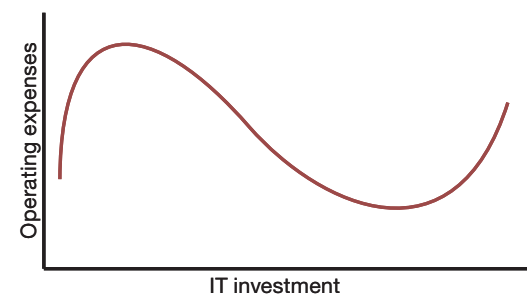
The effects of adding new systems will continue to mirror such step-function investments, though as the level of experience and infrastructure in a hospital rises, this effect may be ameliorated. For example, although the costs to obtain and implement a new advanced clinical information system are significant, a hospital implementing such a system would typically already have the required infrastructure and staff capable of supporting its procurement and implementation. In this case, the shape of the operating expense/IT investment curve might be more like that shown in Figure 7.

Figure 7: Return-on-Investment Scenario Reflecting Startup Costs



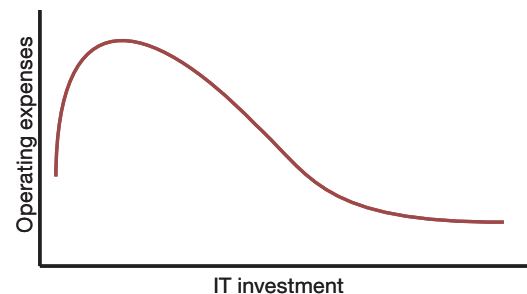
IT investment may also have a point of diminishing returns. As Figure 8 shows, the initial startup costs for the hospitals at the lower end of the IT investment axis are reflected in the steeply rising operating expenses. These increased costs subsequently tail off and begin to fall as the level of IT investment reaches an inflection point. It is unlikely, however, that operating expenses would continue to fall indefinitely as IT investment continues. At the inflection point, operating expenses could be expected to begin to rise again.

Figure 8: Point of Diminishing Returns Followed by a Rise in Costs



Conversely, as organizations with high levels of IT investment slow their spending, implement mature organizational controls on additional expenditure, and gain skills in leveraging IT investments to full effect, the operating cost curve may simply tend to flatten, rather than begin to rise again. (See Figure 9.)

Figure 9: Point of Diminishing Returns



In summary, our current study builds upon prior research in several important ways:

- Our use of multiyear time data partially avoids the weaknesses of cross-sectional studies, enabling inferences to be drawn about whether investment in IT causes economic benefits¹⁵ that cannot be drawn from single-year studies, which can show only that certain factors tend to be associated with each other.
- The use of a more fine-grained and precise metric of IT adoption than that used by Borzekowski or Atkinson and Cockerill enables more precise analysis of where on the IT investment scale effects occur, and this adoption metric enables the exploration of the effects of implementing specific types of applications.
- The use of more powerful statistical techniques can increase confidence in the results.
- We believe these factors contribute significantly to the value our approach can bring to the question at hand.

15. The claim that IT “causes” business performance improvements could be a very strong and potentially contentious claim in economics. We use the term here in its popular, rather than strict economic, sense to imply that we are exploring whether IT investment appears to contribute to performance gains or merely reflects performance gains and is perhaps enabled by them.

Results

The goal of the PricewaterhouseCoopers and Wharton School study was to examine the relationship between IT investment and hospital performance. We used the econometric analysis described earlier and focused our initial investigations on hospital cost efficiency, presenting most of the results as a relationship between IT investment and hospital costs.¹⁶ Further, because costs inevitably rise as organizations become larger (in general, a 400-bed hospital will have a larger cost base than a 200-bed hospital), we present the results as costs (operating expenses) per bed.

Third, we also show how our results differ when IT investment is separated into administrative and clinical application categories (based on the actual IT applications reported at our sample hospitals). Finally, we will demonstrate a significant relationship between mortality rates and IT investment.

Basic Observations on Hospital Costs

Table 10 shows average total hospital operating expenses (per bed) for our hospital panel overall and can be used

Table 10: Average Hospital Operating Expenses per Bed

	1999	2000	2001	2002	2003	2004
Operating expenses						
For-profit hospitals	\$345,723	\$374,385	\$407,608	\$448,105	\$531,519	\$575,313
Not-for-profit hospitals	\$461,478	\$495,337	\$527,640	\$583,828	\$629,757	\$681,500
All	\$438,001	\$472,010	\$504,084	\$557,533	\$611,658	\$661,126
Number of hospitals						
For-profit	322	295	309	294	282	306
Not-for-profit	1,309	1,249	1,270	1,235	1,289	1,303
All	1,631	1,544	1,579	1,529	1,571	1,609

First, we show the relationship between costs (operating expenses) per bed and IT investment as captured by the economic model, which explicitly incorporates other contributors to hospital performance. Second, we present results in a manner that distinguishes between for-profit and not-for-profit hospitals. It is important to avoid simplistic comparative conclusions between these sectors; we make this distinction for a number of reasons. Studies—including several sophisticated studies of technical efficiency—have suggested that the fundamental economic behavior of the two sectors may be different.¹⁷ Moreover, prior research has hinted that the two sectors take different actions and have different goals for IT benefits realization. For that reason, we included for-profit and not-for-profit status as an explanatory variable in our economic model.

to illustrate three initial observations. First, operating expenses¹⁸ increase over the 1999 to 2004 period. Second, year per year, not-for-profit hospitals have higher costs per bed than for-profit institutions. Lastly, not-for-profit hospitals in our sample outnumber for-profit hospitals by a factor of about five.

Basic Relationship between Hospital Performance and IT Investment

To explore the relationship between hospital performance and IT investment more deeply, we used our economic cost model in a more thorough statistical analysis.¹⁹ The results that follow are presented in a sequence that we believe develops the argument in a step-by-step manner. We initially present results for overall IT investment, looking for effects that reflect IT values in the same year as the

16. We also adjusted the model and solved the equations for productivity instead of cost efficiency, with broadly the same results as we report here. Additionally, the results were consistent when we used both a simple application count as our IT measure and when we used the Spetz-Saiden index.

17. See S. T. Parente and R. L. Van Horn, "The Value of Hospital Investment in Information Technology in For-Profit and Not-For-Profit Hospitals," *Health Care Financing Review*, Winter 2006/2007.

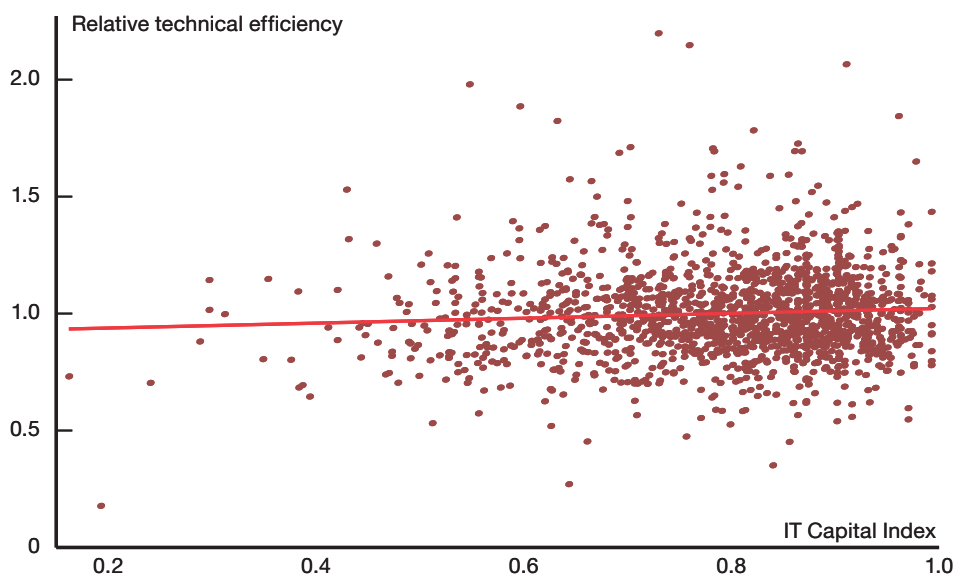
18. Not adjusted for inflation.

19. All associations described herein are statistically significant at the 0.05 level unless otherwise noted.

operating expense (and other business parameter) data. These results are from a simple comparative efficiency analysis, using a production function (as opposed to the cost function used subsequently).

Figure 10 illustrates the basic relationship between hospital performance and IT investment across all the hospitals in our sample panel data. The outcome is encouraging, because it is similar to the pattern captured by the analysis of Brynjolfsson and Hitt (compare with Figure 1 on page 7) of the impact of IT on industry-wide productivity. Figure 10 shows the relationship between IT investment

Figure 10: Relationship between Relative Technical Efficiency and IT Investment



(as measured by our IT Capital Index and expressed as a relative score) and technical efficiency.²⁰ As illustrated in Figure 5 on page 19 and described in the related discussion, technical efficiency—sometimes referred to as productivity—means maximizing output (adjusted patient days) for a fixed input (for example, employees, beds). Cost efficiency means minimizing costs for a given level of output. The two notions can be seen as different facets of the same concept.

For the initial analysis, we evaluated the relationship between two metrics: relative technical efficiency and

20. The technical-efficiency relationship approximates the inverse of the cost-efficiency relationship. Although not shown here, the underlying statistical analysis revealed a convex pattern in the technical-efficiency data that is consistent with the concave pattern shown subsequently in the cost-efficiency data.

IT investment. Relative technical efficiency was computed from the individual hospital technical-efficiency scores—ranging from 0 to 1—for each of the hospitals in our sample using the production form of the model of hospital function described elsewhere in this paper.²¹ We then calculated the average of these scores across all hospitals in our sample. Each hospital’s relative efficiency score is computed by dividing its technical efficiency by the sample mean. Thus, the efficiency analysis is developed using the same control variables as the cost-efficiency model except IT, solved for efficiency rather than cost. IT investment is also expressed as a relative score.

Although there is an effect here, the value of the correlation coefficient in the graph is 0.0712, which means that a hospital’s level of IT investment explains only about 0.5 percent of the variation in efficiency. During a regression analysis in respect of efficiency and the IT Capital Index, we calculated a coefficient of 0.1079 (positive) with a t-statistic of 2.86, which is significant at greater than the 0.01 level.

This result is not large, but it suggests that the data may contain evidence of productivity effects associated with IT. This effect was an early-stage result, implying that there is a relationship that may be characterized more deeply using more advanced techniques (such as the modeling approach we adopted). To explore the effects of IT investment more deeply, and to assess whether the effects are large enough to suggest a prima facie case for additional investment in IT

by hospitals, we applied the more advanced econometric techniques described in the section “Overview of Our Economic Model” on page 20 to analyses of cost efficiencies.

For the preceding analysis, we used relative technical efficiency as our measure of hospital performance. This

21. To calculate technical efficiency, we used the economic model (see the Appendix), which expresses hospital performance as a function relating inputs, outputs, and other factors. Our output measure consisted of adjusted patient days, and our input measures were capital and FTE employees. We also take into account the same hospital characteristics as in our expanded model and use a translog production function akin to our cost function. Using stochastic frontier analysis, we calculated the technical efficiency (productivity, for example) of each hospital in our sample on a scale ranging from 0 to 1. These scores were standardized by the sample mean and plotted against IT Capital Index scores.

metric requires fewer assumptions about potential management behavior differences between different sectors of the hospital industry, and it is simpler to undertake. In subsequent analyses, we used a cost-efficiency metric. We focused on costs for two reasons. First, the assumption that the hospital industry is more focused on cost reductions (for example, lower costs per unit of output) than maximizing patient throughput is easier to sustain across all sectors. Second, there are reasons based in economic theory to prefer a cost function to a production function. (See Appendix: Economic Model on page 38.)

In a PricewaterhouseCoopers analysis published in early 2007, *The Economics of IT & Hospital Performance: A Population Study Reveals Challenges and Opportunities*, we consistently found a curvilinear relationship between IT investment (as measured by our IT Capital Index scale) and hospital costs (operating expenses per bed). Low levels of IT investment were associated with relatively low costs. Increasing levels of IT investment were associated with increasing costs until a tipping point was reached, beyond which additional IT investment was associated with a reduction in costs. Costs at the high end of the IT investment curve, however, did not return to the levels at the starting point of the curve. In addition, we found a latency effect: the cost reduction associated with increased IT was typically greater two years after IT acquisition. In general, for-profit hospitals showed greater cost reductions associated with IT investment than did not-for-profit hospitals. Investments in both administrative and clinical applications were associated with lower costs; however, benefits associated with clinical applications became apparent only when the two-year latency was introduced. These findings were rich in nuance, often involving interactions among hospital type (for-profit vs. not-for-profit), IT investment type (administrative vs. clinical), and latency effects.

For the current analysis, we updated our methodology by making changes to our sample panel of hospitals and by refining our economic model. The hospital data sample now includes hospitals that have fewer than 100 beds. To take into account variation introduced by heterogeneity in the “product line” offerings among hospitals, we added a scope of services factor to our economic model. We also explicitly adjusted the number of hospital beds (for inpatient and outpatient revenues) as a control for potential disparities in operational costs per bed resulting from differing proportions of inpatient/outpatient services. This updated methodology provides the basis for the results and conclusions in this paper.

Econometric Analysis of IT Investment and Cost Efficiency

We initially applied our economic model to analyze IT investment and cost efficiency across all hospitals in the sample, using operating costs during the same year as reported IT system acquisitions. Figure 11 illustrates how hospital operating expenses per bed on the Y-axis (costs, as calculated using our economic model) change across increasing levels of the IT Capital Index (our relative measure of IT investment on the X-axis). This analysis reveals an effect described by a concave line in Figure 11, suggesting that higher levels of IT investment are initially associated with higher costs per bed (as shown in the three red and brown shaded lines). Those costs rise until IT investment reaches a tipping point; that is, until for-profit hospitals exceed 0.55 on our IT Capital Index scale and not-for-profit hospitals exceed 0.88. Once hospitals achieve these levels, then costs per bed trend downward, and that trend is more aggressive in for-profit hospitals. Only in for-profit hospitals did operating expenses associated with higher IT Capital Index levels fall below expenses at the beginning of the curve.

Throughout the study, we generally found that operating expenses per bed were significantly lower for for-profit hospitals compared with not-for-profit hospitals.²² Prior studies have reported several differences between the two sectors that may help explain this result. Not-for-profit hospitals operate with a broader societal mission, typically providing larger volumes of uncompensated care, research, and other services. For this and other reasons, not-for-profit hospitals may be slower to drop services or withdraw from markets in response to declining profitability. In addition, not-for-profit hospitals often serve as incubators for entirely new services, using philanthropy and cross-subsidies to finance the development of services for which payment systems have not yet been regularized.²³

Figure 11 also shows the cumulative distribution of for-profit and not-for-profit hospitals in our sample, as shown in the two blue-shaded lines. Although the cumulative distribution lines for both hospital types are similar, a majority of for-profit hospitals is above the tipping point (beyond which increases in the IT Capital Index are associated with decreased operating expenses), while the majority of not-for-profit hospitals is below the tipping point.

To facilitate interpretation of these and other curves presented later, Table 11 shows hospital operating expenses from selected points across the IT Capital Index scale.

22. As indicated in Table 8, these differences were observed in our sample data panel and are not a result of applying our economic model.

23. See M. Schlesinger and B. H. Gray, “Statement for the Record to the House Committee on Ways and Means,” May 26, 2005.

Figure 11 and Table 11 depict operating expenses initially rising with increasing IT investment, leveling off at a tipping point, and then gradually decreasing at higher levels of IT investment. This concave relationship between IT investment and total operating costs is consistent with the observation that initial increases in IT capital may entail significant startup expenses (networking infrastructure, recruitment of IT staff) that increase costs despite any efficiency gains that the IT applications might provide. Arguably, this is a necessary cost of doing business—it is difficult to imagine a hospital providing effective services without a reasonable administrative information systems infrastructure. The curve also suggests that eventually, at higher levels of existing IT investment, adding more IT investment may be associated with reduced costs per bed even in same year analyses, especially in for-profit hospitals.

Prior studies on hospital costs suggested that the effect of IT on cost efficiency was most apparent after a three- to five-year lag period. Additionally, studies outside healthcare have also shown that the benefits of IT may intensify over time, presumably as the organization gains skills in leveraging the technology implemented and as organizational work processes adapt to new ways of doing business afforded by information systems.

We also examined the effect of time lags on the relationship between the IT Capital Index and hospital operating expenses by relating each year's hospital performance statistics with IT Capital Index values from one and two years earlier. The underlying statistical technique ensures that any performance-changing effects of IT that are apparent more quickly (that is, same-year effects in the one-year time lag, or effects in the same-year and within one year in the two-year

Figure 11: Effect of IT Capital Index on Operating Expenses per Bed by Hospital Type

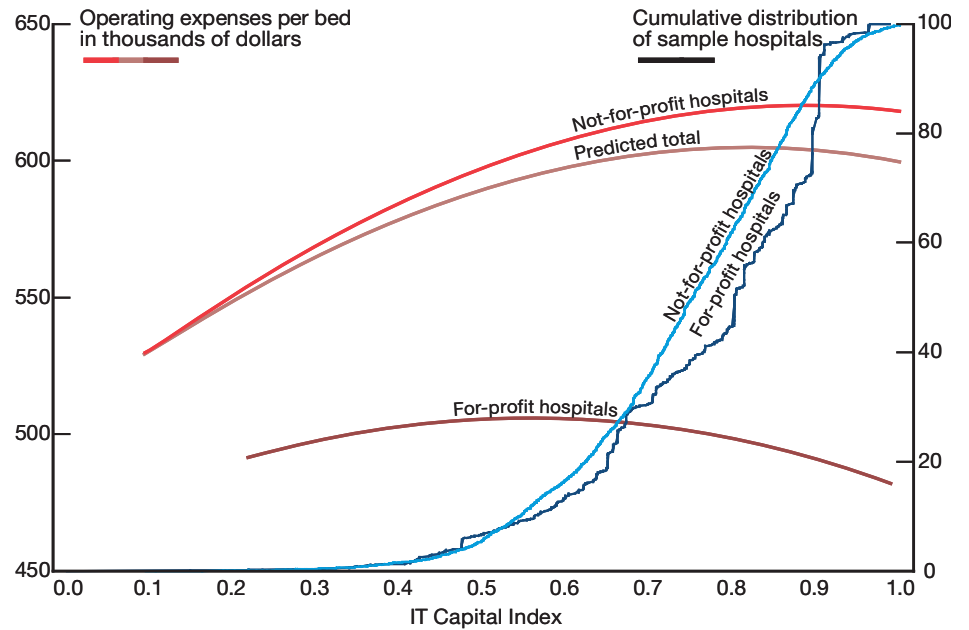


Table 11: Operating Expenses per Bed at Sample Values of IT Capital Index

IT Capital Index sample values	Operating expenses per bed for an average hospital	
	For-profit hospitals	Not-for-profit hospitals
0.200	490.23	551.58
0.400	502.86	585.14
0.600	505.60	607.90
0.800	498.06	619.20
0.825	496.43	619.70
0.850	494.68	620.04
0.875	492.64	620.17
0.900	490.53	620.01
0.925	488.27	619.84
0.950	487.77	619.36
0.975	483.31	618.69
Median IT Capital Index	495.97	618.05
Mean IT Capital Index	496.40	614.70

time lag) are implicitly included. Our analysis limited the lag period to two years (which may not be long enough for time effects to appear), because the analytical technique used here does not support calculation of longer time-lag effects.

Introducing a two-year time lag shifted the tipping point to the left for for-profit hospitals, so that the cost reductions associated with IT appeared at lower levels of IT investment. No other effects of introducing the lag were observed. (See Figure 12.)

A number of possibilities can explain the apparent attenuation of time-lag effects between our prior study and these findings. The manner in which individual hospital IT profiles change over time makes simple time-lag analysis difficult, as does the constantly changing mix of potential applications. Additionally, application name changes over time may also create challenges in year-to-year comparisons. Professional experience, other research findings, and our previous studies all suggest that a time lag between system implementation and maximum benefits should exist. This is an area for potential continuing research.

The results in Figure 12 are also shown in Table 12. IT is not a uniform product or service that can be acquired in continuous or homogeneous quantities, such as concrete or electricity.²⁴ It generally must be acquired as entire applications. Ideally, we would like to be able to isolate the impact of particular application types, rather than using only an aggregate measure of total IT. To further examine the relationship between IT investment and cost efficiency, we calculated the IT Capital Index separately for administrative and

Figure 12: Effect of Two-Year Lagged IT Capital Index on Operating Costs per Bed

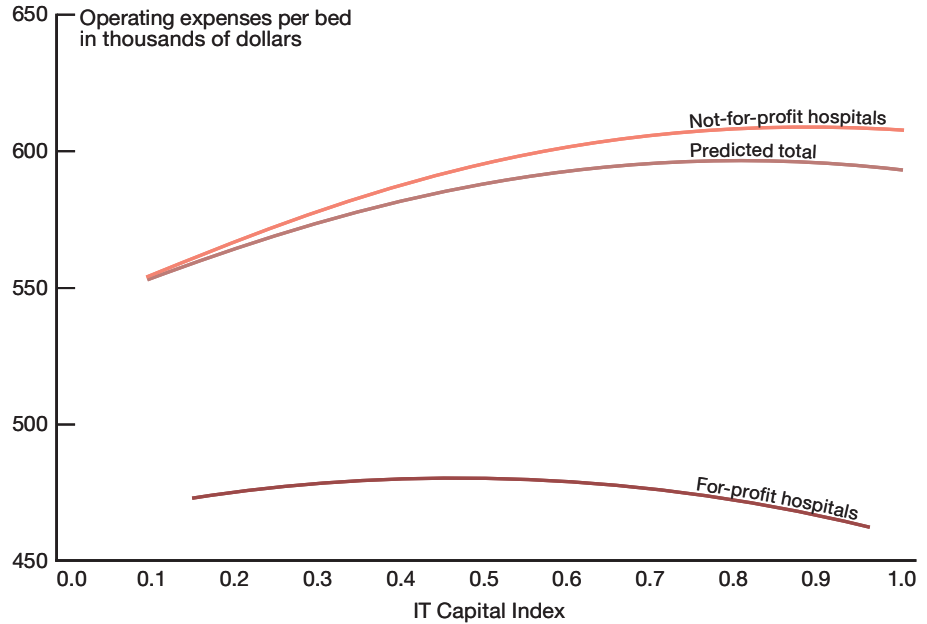


Table 12: Effect of Two-Year Lagged IT Capital Index on Operating Costs per Bed

IT Capital Index sample values	Operating expenses per bed for an average hospital	
	For-profit hospitals	Not-for-profit hospitals
0.200	475.29	567.16
0.400	479.98	587.49
0.600	478.85	601.24
0.800	471.99	607.94
0.825	470.74	608.27
0.850	469.41	608.48
0.875	467.99	608.59
0.900	466.49	608.57
0.925	464.89	608.44
0.950	463.23	608.20
0.975	462.06	607.84
Median IT Capital Index	471.92	606.28
Mean IT Capital Index	472.73	604.44

24. In the future, emerging IT service models such as utility computing or application service provider (ASP) may change this observation.

clinical components, as described earlier. (See Table 9 on page 18.) We used the same technique as for the IT Capital Index scoring, but separately for clinical applications and administrative applications. As before, we initially examined same-year results; that is, the impact of IT changes in the same year that an application was acquired. Subsequently we examined the effect of time lags on these application subgroups.

In the same-year results for administrative applications only, the form of the results curve remains unchanged for not-for-profit hospitals. (See Figure 13²⁵ and Table 13 and compare to Figure 11 on page 27.) In other words, IT investment is associated with modestly lower operating expenses, but only after hospitals have made a sufficient level of investment. In contrast, when administrative applications are singled out, for-profit hospitals²⁶ show efficiency gains at even the lowest levels of IT investment, and the tipping point is now almost at the beginning of the curve. And, in for-profit hospitals, operating expenses at the high end of the IT investment curve are clearly lower than at the low-investment starting point.

Figure 13: Effect of Administrative IT Capital Index on Costs by Hospital Type

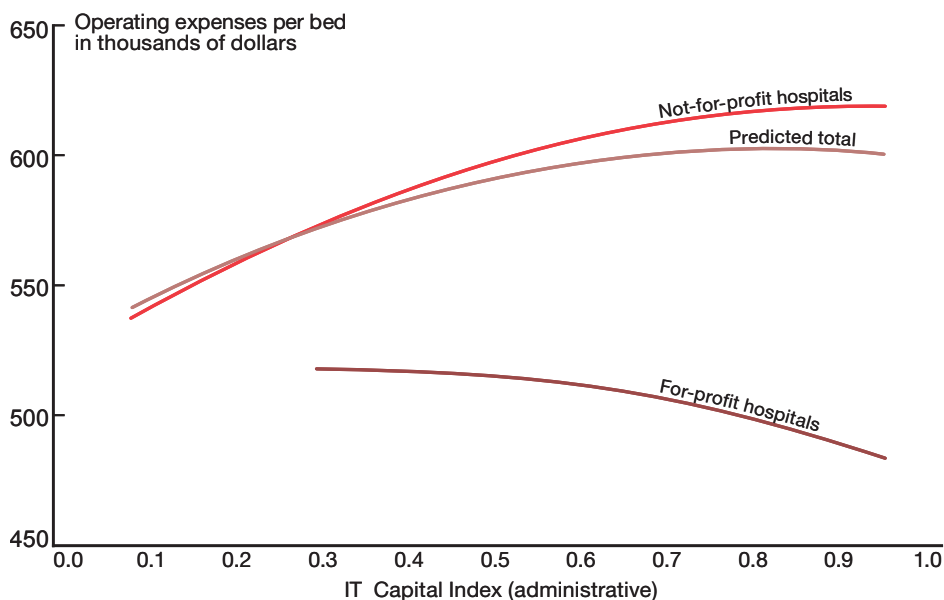


Table 13: Effect of Administrative IT Capital Index on Costs by Hospital Type

IT Capital Index sample values	Operating expenses per bed for an average hospital	
	For-profit hospitals	Not-for-profit hospitals
0.200	516.14	557.11
0.400	517.37	584.55
0.600	513.01	604.32
0.800	501.47	615.98
0.825	499.55	616.84
0.850	497.52	617.56
0.875	495.40	618.15
0.900	493.17	618.60
0.925	490.84	618.91
0.950	488.42	619.09
0.975	485.90	619.13
Median IT Capital Index	493.43	616.83
Mean IT Capital Index	496.70	614.67

25. The lowest apparent point on the IT Capital Index for the administrative applications appears in some charts to be at different levels due to the manner in which the statistical program STATA calculates, selects, and ignores outliers.

26. For-profit hospitals in our panel composed a more homogeneous group than not-for-profit hospitals, as reflected in their smaller variances in the input and output variables used for our economic model. Statistically, this homogeneity allowed us to more easily draw conclusions about the relationship between IT investment and operating expenses for the for-profit sector.

Clinical applications showed little or no efficiency gains in not-for-profit hospitals. (See Figure 14 and Table 14.) Increasing levels of clinical IT investment did not lead to operating expense reductions. By contrast, in for-profit hospitals, clinical applications appeared to improve cost efficiency, once beyond a tipping point high on the IT Capital Index scale.

We gained further insights by subdividing the administrative and clinical applications into finer-grained subcategories as delineated in Table 9 on page 18.

- Base administrative and financial applications (such as registration, billing, eligibility, and staffing) had a positive effect on cost efficiency in for-profit hospitals, but were associated with increased costs in not-for-profit hospitals for all levels of IT investment.
- Medical record applications (for example, abstracting, chart tracking/locator, and so forth) were not associated with reductions in costs in the for-profit or not-for-profit hospitals.
- Financial decision support (that is, retrospective decision support, flexible budgeting, and so forth, as opposed to proactive clinical decision support) applications were associated with cost-efficiency improvements only in for-profit hospitals, where the effects were notable.
- Among clinical applications, ancillary departmental applications (such as laboratory and radiology) were not associated with cost-efficiency gains in not-for-profit hospitals or for-profit hospitals.
- Clinical departmental applications (such as cardiology and surgery) were associated with cost-efficiency gains in for-profit hospitals but not in not-for-profit hospitals.

Figure 14: Effect of Clinical IT Capital Index on Costs by Hospital Type

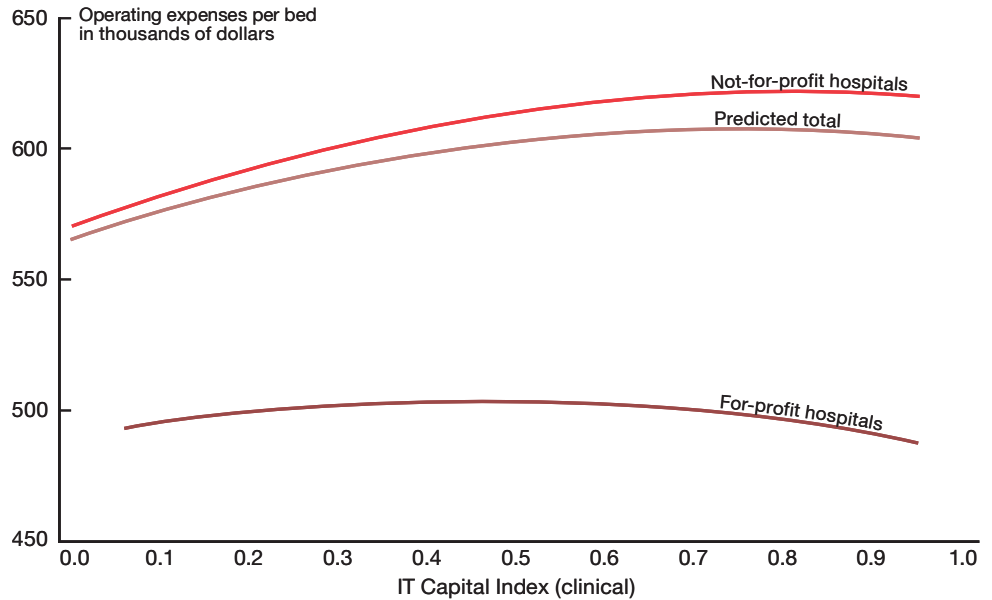


Table 14: Effect of Clinical IT Capital Index on Costs by Hospital Type

IT Capital Index sample values	Operating expenses per bed for an average hospital	
	For-profit hospitals	Not-for-profit hospitals
0.200	499.19	591.30
0.400	503.35	606.85
0.600	502.79	617.00
0.800	497.55	621.46
0.825	496.57	621.61
0.850	495.52	621.66
0.875	494.40	621.63
0.900	493.20	621.52
0.925	491.94	621.29
0.950	490.60	620.98
0.975	489.22	620.59
Median IT Capital Index	497.21	620.32
Mean IT Capital Index	497.84	616.85

- Enterprise clinical applications (for example, clinical documentation, order communication/results, and so forth) were associated with cost-efficiency improvements in for-profit hospitals, but the effects in not-for-profit hospitals were minimal.

Table 15 summarizes this pattern of results.

In summary, the situation is complex. Hospitals that have minimal IT appear to be facing significant cost increases as they contemplate investment in IT, though they represent a very small share of US hospitals. While IT investment may initially appear to have a cost-increasing effect, above a certain level of IT capital investment—a tipping point—the impact levels off and is associated with cost reductions. Thus, incremental investments are associated with either no increase in costs or actual reductions in hospital operating expenses.

An alternative way to reveal potential cost decreases associated with IT investment is to calculate the maximum operating expense differential between two points on our IT investment curves—operating expenses at the tipping point and operating expenses at the point of maximum IT Capital Index (the right end of the curve). Table 16 shows

these results (same year and for all applications), which clearly indicate that IT investment above the tipping point was associated with decreased costs, particularly for for-profit hospitals.

The question of whether IT generates a return on investment is still not easy to answer. As portrayed in our initial results, the overall effect of IT on not-for-profit hospitals is cost increasing because the operating expenses do not appear to return to pre-IT levels. However, it is important to note that above a certain level of IT investment, the overall effects on operating expenses appear to be cost reducing—a finding consistent with research in other industries. We found that the operating expenses of for-profit hospitals at the high end of the IT investment curve were the same or lower (especially for administrative applications) than hospitals at the lowest IT levels. For any individual hospital, the business case for additional IT investment may depend on its starting point on the axis of IT investment. Hospitals at or near the tipping point may more easily justify benefiting from the sunk costs of IT investments already made. Another possibility is that some increase in IT investment may simply be driven by business

Table 15: Summary of IT Effects by Application Subgroups

Application grouping	For-profit hospitals	Not-for-profit hospitals
Base administrative and financial	Reduced costs	Increased costs
Medical records	Increased costs	Increased costs
Financial decision support	Reduced costs	No effect
Ancillary departmental	No effect	No effect
Clinical departmental	Reduced costs	No effect
Enterprise clinical	Reduced costs	Minimal or no effect

Table 16: Cost Reductions by Hospital Type (same-year analysis)

	For-profit hospitals	Not-for-profit hospitals
Average cost per bed at IT Capital Index tipping point	620	506
Average cost per bed at maximum IT Capital Index	618	482
Maximum cost reduction	2	24

All costs in thousands of dollars per bed

necessities that did not decrease costs as measured by our study.

What do these results mean to the CEOs of different types of hospitals? This important question requires a subtle answer. Some caveats must be kept in mind when looking at these results. First, the analysis we used in this report represents an amalgam of the data from many hospitals. This gives the study real statistical power, but inevitably some hospitals will gain greater cost-reduction benefits than might be apparent from the charts, and other hospitals may experience fewer benefits. While future research may allow us to isolate the especially highly performing hospitals and seek to determine the basis upon which they accomplish such results, that was not the purpose of the current study.

The IT Capital Index we developed is a continuous scale. In any hospital, the decision to acquire a software application entails a step-increase in IT capital. The model we have developed does not yet enable the examination of the effects of the presence or absence of individual applications, because the number of cases where hospitals' application configurations have unique differences is not large enough to support the derivation of statistically significant conclusions about the effects of individual applications. In response, we defined and analyzed the effects of application groups as shown in Table 9 on page 18.

The results of our analysis by application group showed that investment in clinical systems does not appear to have a dramatic impact on costs in not-for-profit hospitals. However, the arguments in favor of IT investment typically entail consideration of the quality-improving effects of clinical IT, not just the effects on costs. An important consideration is the possibility that IT investment (especially in clinical applications) may increase care quality without a change in costs to the individual hospital. (Compare with Figure 5 on page 19, lower right.) Although this paper focuses on cost efficiency, we also applied some of our research techniques to an initial exploration of the effect of IT investment on clinical quality.

Econometric Analysis of IT Investment and Hospital Quality of Care

Data on quality of care is difficult to obtain. No national standard data sets have been collected in a systematic way, covering all patients, for a sufficient period of time, to enable the ideal study to be conducted. Moreover, at least one recent study indicated that available national quality performance indicators are not necessarily strong

predictors of care outcomes (such as mortality rates).²⁷ Recognizing these limitations, we applied our economic model to a basic quality of care metric to see if the model might yield useful results.

We explored the relationship between IT investment, as measured by our IT Capital Index score, and mortality, as reported in the MEDPAR²⁸ data set. Mortality is not necessarily a good measure of quality of care, for many reasons that are well described in the literature. Hospitals that attract the most difficult cases, for example, may be providing the highest quality of care, but still demonstrate a high mortality rate because of the difficulty of the cases they treat. Nevertheless, mortality is accepted as being a part of a stable of measures that together may form a reasonable guide to quality of care. We performed this analysis in two stages. First we examined the relationship between IT investment and mortality scores, and then we adjusted our economic model to take account of mortality as another output of a hospital. Recognizing that mortality rates do not comprehensively measure quality of care, we used mortality rates adjusted for risk, case mix, and state average to examine if at least a directional impact of IT investment is detectable.

IT Investment and Its Relationship to Quality of Care

Figure 15 shows the results from plotting the IT Capital Index score against the state-adjusted²⁹ mortality rate for each hospital using 2004 data from our panel. This scatter plot³⁰ shows that increases in the IT Capital Index were associated with decreases in adjusted mortality rates.

The results reveal an association between high IT investment and lower mortality rates. Table 17 shows adjusted mortality rates (as deaths per thousand admissions) for the top and bottom 20 percent of hospitals (determined by their IT Capital Index score), and also groups hospitals according to whether they fall into the top or bottom half of the cost distribution for the sample. This relationship suggests a positive association between IT investment and quality of care, at least among hospitals that have high costs. Hospitals that have low costs tended to have lower investments in IT, which may account for the lack of a similar positive association. These statements are

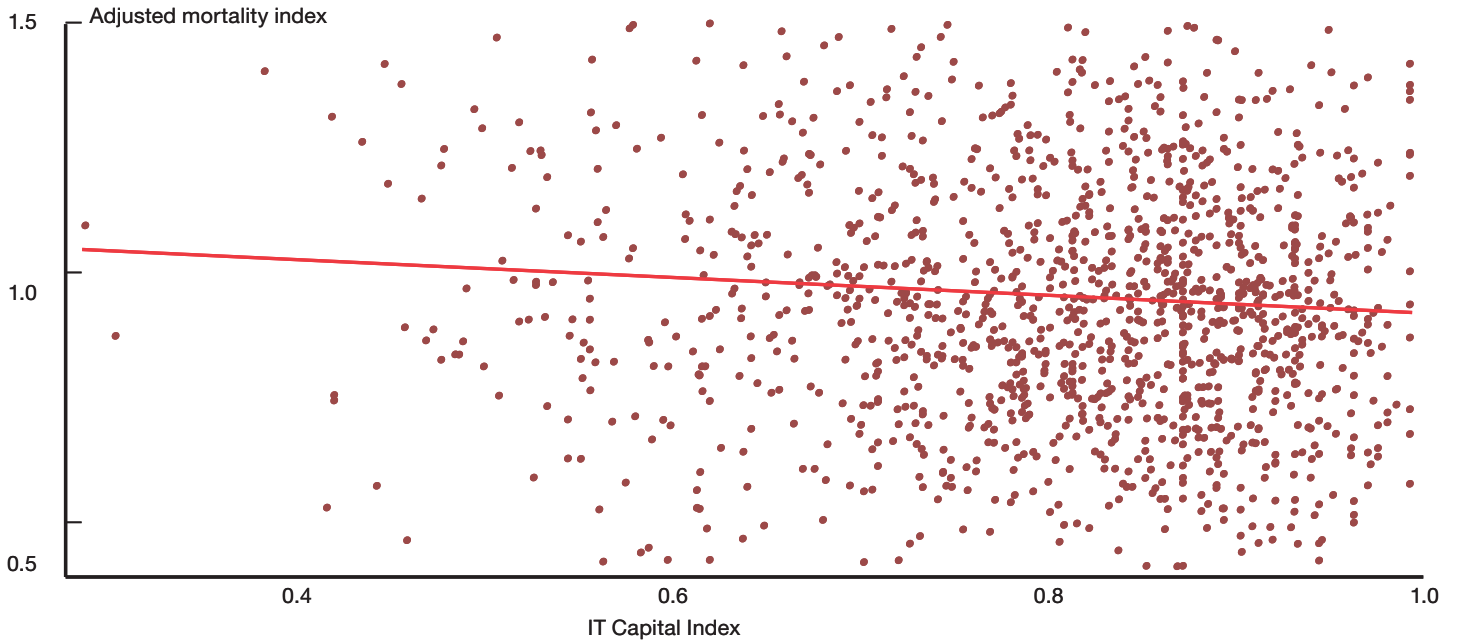
27. R. M. Werner and E.T. Bradlow, "Relationship between Medicare's Hospital Compare Performance Measures and Mortality Rates," *Journal of the American Medical Association* 296 (December 2006): 2,694–2,702.

28. The MEDPAR data set is maintained by the Centers for Medicare and Medicaid Services (CMS) and contains information for 100 percent of Medicare beneficiaries using hospital inpatient services. Data is provided by state and then by DRG for all short-stay and inpatient hospitals.

29. Each hospital's mortality score was standardized by dividing it by the state mean.

30. The scatter plot does not show points above 1.5 or below 0.5 on the mortality index axis.

Figure 15: Adjusted Mortality by IT Capital Index, 2004



conjecture, and the results warrant deeper investigation using more precise and accepted definitions of quality.

As shown in Table 17, mortality rates for hospitals that have high costs and high IT were significantly³¹ lower than for hospitals that have low costs (both low and high IT groups). In addition, mortality rates for hospitals that have high costs and high IT were lower than for hospitals that have high costs and low IT; however, the statistical significance (0.07) fell just short of the 5 percent level. For example, in a 300-bed hospital experiencing 20,000 admissions per year, the impact of the IT-related investment might mean as many as 20 fewer deaths per year. Although the effect is small, it is consistent with the industry perspective that hospitals investing in IT might decrease mortality

Table 17: Hospital Mortality Rates by Cost and IT Groups

	Low IT (bottom 20%)	High IT (top 20%)
High cost (top 50%)	41.48	39.18
Low cost (bottom 50%)	44.14	43.16

National average rate for population of hospitals in our study: 41/1000

levels without necessarily increasing costs. More research would be required to establish the causal relationships involved.

Treating quality as an important variable is customary when assessing productivity and cost efficiency. For example, one organization may produce only four widgets per dollar compared to the industry average of six, but the quality of those four widgets may be significantly higher. A better basis for comparing these two organizations would be to use a quality-adjusted widget output, which would—in effect—hold quality constant and thus enable a more proper comparison of efficiency metrics. For that reason, we furthered our analysis by including a mortality factor in the economic model described earlier, in effect expanding our concept of cost to include a crude measure of quality in a four-year data panel.³²

Adding a mortality factor in our economic model had only a slight effect on the observed relationship between IT investment and costs. The factor intensified the relationship between IT investment and operating expenses in for-profit hospitals. The effect in not-for-profit hospitals was negligible. This small overall effect, however, is consistent with the view that mortality rates alone do not represent a strong proxy for quality of care. In future research, a more precise measure of quality may yet reveal a more significant effect.

31. Significant at the 5 percent level using the Welch test.

32. Our cost-efficiency analyses were based on a five-year panel of data. However, we had mortality data only for 2001 to 2004.

Characteristics of Results

Initial reactions to our study's results may be a degree of disappointment that the evidence is not more conclusive in its assertion of an economic benefit to IT investment. Why might the impact be so modest? Several possible explanations follow:

- **Data variance**—Hospitals may vary in how they submit data, and the methods of collecting additional data may alter the data on which we rely, introducing random error that reduces the apparent effects of IT.
- **Data bias**—If the data has a bias not detectable by our statistical methods, that bias could obscure a stronger relationship between IT and cost.
- **Conservative economic model**—The approach to economic modeling we used is deliberately conservative in its derivation of the impact IT has on cost efficiency and quality. This approach underestimates the significance of effects that may actually be present.
- **Incomplete IT installation or underutilization**—Some hospitals have reported acquiring systems but have not yet truly begun installation, or they have implemented systems that are not fully being used.
- **Lack of process redesign**—Hospitals may not have made the investments in process redesign that are necessary to ensure the realization of potential benefits.
- **Different targeted goals**—Hospitals may have in fact achieved the goals they targeted with IT capital investments, but the outcomes we measured were not part of their targets. For example, they may have targeted convenience or customer experience factors that do not reduce costs.
- **Reinvestment of savings**—Hospitals may have achieved the levels of cost savings in process areas they targeted, but they chose to reinvest those savings in other hospital operations and therefore did not reduce their total costs.
- **Benefits accrue to others**—Benefits may have been realized that do not appear in the factors included in our economic model because they accrue to others, such as hospital payers.

The data available for the study did not enable us to distinguish among these hypotheses. However, professional opinion would support the contention that hospitals are likely to overstate the level of automation reported to the HIMSS Analytics survey, and that hospitals have frequently

not undertaken the significant process redesign efforts needed to realize the benefits that they theoretically could achieve.

A comparison of our current findings to our initial analysis showed that the patterns of results were consistent, with two exceptions.³³ In our updated economic model, hospitals that have invested in IT accrued benefits during the same year as the IT acquisition; we found only limited evidence that the effects of IT increased over time. The new analysis also revealed cost reductions at lower levels of IT investment for for-profit hospitals, particularly for administrative applications.

The results presented in this report provide new evidence that can guide policymakers and hospital decision makers as they consider healthcare IT investments. We shall explore these in the following section.

33. Additional analysis indicated that these exceptions were likely due to introducing the hospital bed size adjustment (for inpatient and outpatient revenues) into the economic model.

Conclusions

These results illuminate the link between IT investment and organizational performance in US hospitals. Our economic analysis, our unique IT investment measure, and the representative nature of the data sample overcome several of the shortcomings of previous work in this field, and allow a more detailed view of the multiple interacting factors involved. The results, however, while stable across a number of statistical treatments, are complex. The following highlight the main takeaways:

- **Higher investment in IT is associated with improved business performance**—This analysis, which incorporates real performance data from almost 2,000 US hospitals and a more precise measure of IT investment, can be considered as close a measure of IT's real-world impact on hospital performance as has yet been published. We found conclusive evidence that higher levels of IT investment are associated with more business benefit. However, the degree of the effect, while statistically significant, is modest. The potential cost savings for hospitals averages to a small percentage of the operating costs per bed. This savings could nevertheless rise to the level of millions of dollars per year for a large hospital. Additionally, apparent quality effects (that is, lower mortality), although not fully explored in this study, appear to be detectable.
- **Until IT investment reaches a threshold, total operating expenses increase in hospitals that have little IT**—The study clearly indicates that those few hospitals that are low on the IT Capital Index scale will experience increases in total operating expenses as they bring more IT online, at least until they reach an overall threshold level. (An exception to this was investment in administrative applications by for-profit hospitals, which was associated with reduced costs even at low investment levels.) Although these greater costs have reasonable explanations, hospitals in this situation face a daunting prospect if they must justify IT investments on the basis of near-term payback.
- **For-profit and not-for-profit hospitals show consistent differences in costs**—The study demonstrates a consistent difference in costs between for-profit and not-for-profit hospitals. For-profit hospitals generally showed lower operating expenses per bed, a finding consistent with aforementioned differences between the two types of hospitals. Moreover, this is the first study to suggest that for-profit hospitals may also be getting more out of their IT investments, especially their administrative applications. This finding may imply a focus on efficiency that goes beyond any baseline causes of cost differences, such as more limited service offerings, different case mixes, or more morbidity in patients entering the facility. One hypothesis is that for-profit hospitals are more likely to be part of a large system that has centralized IT acquisition and thus greater capacity for standardized approaches to application deployment. Also, for-profit hospitals may have shorter-term mandates for cost-effectiveness of investments. Our findings—among others—suggest that the two types of hospitals may have noteworthy differences in their business models, and these differences may include factors that are manifest in our results. Additional research in this area may be fruitful.
- **IT investment has the potential to pay for itself**—As hospitals move up the IT Capital Index scale, they all show at least a leveling off of costs. It is important to note that this leveling off occurs despite the added costs of more IT capital; that is, IT capital at some point pays for itself by displacing costs elsewhere in the hospital. Given the suggestive results about quality (as measured by mortality rates), the fact that new IT capital investments may be cost neutral could be a more persuasive justification for making the investments: improved quality at constant cost per bed.
- **The effect of IT investment has been proven in other industries**—The studies of other industries using similar economic modeling and econometric techniques demonstrated far more powerful effects of IT. Brynjolfsson and Hitt estimate a productivity advantage of IT investment that is five times the cost of the IT investment itself. Overall, then, these results for hospitals are rather disappointing. A likely culprit—that hospitals have failed to take advantage of IT by making more significant process changes in business and clinical activities—cannot be verified by this study and requires future research.
- **Higher levels of IT investment are associated with reduced costs**—As hospitals move into “high adopter” categories—especially those in the for-profit sector—there is strong evidence that they enter a cost-reducing relationship with IT investments. As suggested in our previous research on digitally advanced hospitals (*Reactive to Adaptive: Transforming Hospitals with Digital Technology*, March 2005), this finding is consistent with the idea of network effects—that is, incremental additions of IT contribute directly to the clinical/business processes they are targeting and at the same time make pre-existing IT at the hospital more valuable. We hypothesize that this is caused by the increasingly inter-connected nature of processes made possible by a hospital on the road to complete digitization, or the full automation of clinical care.

Hospitals are gaining significant value from their IT investments, and this study suggests that investments may result in demonstrable cost-reduction and quality-improvement benefits. However, a number of hospitals (especially in the not-for-profit sector) considering new IT investments will be at a point on the IT Capital Index scale that precedes the point where operating expenses begin to fall in response to additional investment. There are also quality improvements to consider—but evidence of that is still in a formative stage. Hospital management should not justify expensive new IT investments purely on the assumption that these investments will create large and rapid paybacks for the organization. If anything, management should use these results to justify moving along the IT investment axis to a position where future IT investments at least pay for themselves.

This study had no access to data describing process change in association with IT investments. However, hospitals that have above-average IT investments likely have large, latent potential for cost efficiencies that could be realized with careful process reengineering. Analyses of other industries show much stronger impacts of IT investment on productivity, and process changes are the primary explanatory factor. Hospitals will need to reexamine their commitment to and investment in process change—both business and clinical—if they hope to capture more benefit from IT investments.

When speaking to hospital executives, vendors of healthcare IT systems should carefully gauge their promises against the reality of what is currently being delivered in hospitals. The cost-per-bed reductions in hospitals that have the highest levels of IT capital might average only 5 percent less than hospitals that have average levels of IT capital.

Vendors should also consider investing in more expansive process redesign and change management services capabilities, and vendors should collaborate more closely with integration partners to help hospitals maximize the use of IT. Implementing IT from a full organizational and process change perspective is in hospitals' direct interest more than ever, especially as data and analyses of the type demonstrated in this study establish that simply buying and installing has only modest effects.

This study also contains messages for policymakers. The evidence presented here illustrates that many hospitals

have significant opportunities to make IT investments that positively affect cost and quality. To that end, policymakers may wish to accelerate initiatives aimed at encouraging investment. However, for some hospitals, the path to reduced costs attributable to IT investment may be an arduous one, a path that could require several years of increased operating expenses in addition to other inevitable challenges of IT projects. Strident exhortations are unlikely to help a hospital in this situation, and a combination of encouragement, incentives, and leadership will be needed.

The modest cost impact demonstrated by this study may spur policymakers to accelerate their initiatives that include pay-for-performance-based compensation schemes. Explicitly compensating hospitals for higher quality will, if our preliminary results are validated with more broad-based studies about quality, create far more incentive for executives to invest in IT than a focus on the traditional business metric of cost avoidance.

It is also important to note that IT may bring value in areas that could not be examined through the methods in this study: impacts on quality, for example, or patient and staff satisfaction, to name just two possibilities. Additionally, cost reductions could be greater than those in our study's results, but hospitals might be passing the savings to payers in ways that the study cannot detect. Considerable recent discussion proposes that while the institution bears the costs of automated systems, many of the benefits accrue to payers, to patients, and to society.

This analysis of hospital data is just a starting point. In particular, the relationship between IT investment and quality of care is an important topic, and one in which the methodological and data challenges are great. Moreover, our study was necessarily constrained to examine US hospitals but not physician groups or other healthcare facilities. Although the results presented in this study indicate promising avenues of quality research, the paucity of consistent, valid, and credible data over a reasonable period of study is nevertheless still problematic. However, as a new emphasis on quality measures appears in more contracts between payers and providers in the United States, this situation is changing rapidly. These additional analyses may be supported in the future by the methods described here.

Appendix: Economic Model

To assess the impact of IT capital on the total production cost in US hospitals, and thereby on productivity, we use a cost function that depends on IT capital (IT), other capital (K), output, and the prices of labor and materials. This approach copes with the shortcomings of the production function methodology, which lacks economic structure and is unable to incorporate profit optimization behavior.

We start by defining the production function as follows:

$$Y_t = f(L_t, K_t, M_t, IT_t)$$

where Y_t is a composite output measure, L_t is labor input, K_t is non-IT capital, M_t is material input, and IT_t is IT capital. Equation 1 is a standard production function, where capital is split between IT and non-IT parts. The production function literature has used a similar structure, but the literature has widely criticized the empirical predictions yielded by production functions, in spite of their simplicity. As D. W. Jorgenson showed in 1971, a single-equation production function results in excessively high input elasticity and marginal productivity. We subsequently use this production function to derive the cost function in our model.

According to the duality concept described by W. E. Diewert and D. McFadden, production functions can be used to specify cost functions from which the demand for factor inputs can be derived from the assumptions of cost minimization and perfect competition. This corrects for the lack of structure in the production function setting.

Besides providing a full economic structure, cost functions have several advantages when used in empirical assessments. As T. C. Marcin notes in the paper “Cost Function Approach for Estimating Derived Demand for Composite Wood Products,” cost functions can be easily computed because the function can be specified from an input process at a given level of output. Further, cost functions are very convenient when specifying empirical functional forms where the quantity of factor demands is unknown.

Another convenient feature of cost functions is that they allow the specification of multiple outputs. This capability is important when studying hospitals, because a variety of different outputs can be identified: patient days, discharges, surgeries performed, outpatient visits, emergency room visits, and so forth. In our preliminary analyses, we began by identifying two different output measures (inpatient discharges and total outpatient visits) but eventually switched to a single output measure (adjusted patient days) that incorporated both the inpatient and outpatient elements of a hospital’s production of outputs. This change did not yield any substantive changes to our results.

The specification of the cost function for our analysis begins with the following general form:

$$VC_t = c(P_L, P_M, K_t, IT_t, Y_{yt})$$

where VC_t is variable cost, P_L and P_M are the variable input factor prices, and K_t is considered the quasi-fixed input in the production. Although it may initially appear unusual to treat capital as fixed in the short run, we felt that this was an appropriate assumption in the hospital industry because our measure of capital (revenue-adjusted bed size) is less easily adjusted than traditional forms of capital.¹ The output variable in the cost function is split into its component parts Y_{yt} , $y + 1 \dots n$, where i is the number of different outputs produced by a hospital at time t .

The function c satisfies the following properties: linearly homogeneous, continuous, and twice differentiable in all of its inputs; non-decreasing and concave in the factor prices; non-decreasing in output; and non-increasing and convex in K_t .

To test the hypothesis that hospitals are effectively using their IT capital, we introduce IT explicitly into the production function. If hospitals use their IT capital efficiently, then IT capital must have a negative effect on total variable costs, just like non-IT capital. By testing whether the cost function is non-increasing in IT capital, we effectively test whether hospitals are maximizing their output along with their IT input.

From two variable inputs of production, we can derive the hospital cost curve as follows:

$$VC = P_L L + P_M M$$

where L and M are cost-minimizing input quantities.

Using Shephard’s lemma and the envelope theorem, the resultant factor demand equations model the use of labor and materials conditional on the level of output. These factor demand equations are the partial derivatives of c with respect to the input prices:

$$\frac{dVC}{dP_L} = x_L(P_L, P_M) \text{ and } \frac{dVC}{dP_M} = x_M(P_L, P_M)$$

where x_i , $i = L, M$ is the input factor demand for labor and materials, respectively.

To choose a functional form for our cost function, c , we follow the example of prior research in the field and utilize a translog function. The use of translog functions allows us to investigate a more flexible form than the simple

1. In our model, adjusting bed size by revenue produced more reasonable estimates of hospital capital, so we used this measure of capital. We tested the model using unadjusted bed size, and it produces no appreciable difference in the results.

Cobb-Douglas setting, by departing from the unitary elasticity of input substitution assumption.

The production structure can be represented by the cost function in Equation 1.

Equation 1:

$$\begin{aligned} \ln VC &= \alpha_0 + \beta_W \ln P_W + \beta_M \ln P_M + Sy; \beta_Y \ln Y + \\ &\beta_K \ln K + \frac{1}{2} \beta_{WW} \ln^2 P_W + \frac{1}{2} \beta_{MM} \ln^2 P_M + \frac{1}{2} Sy; \beta_{YY} \ln^2 Y + \frac{1}{2} \\ &\beta_{KK} \ln^2 K + Sy; \beta_{YW} \ln Y \ln P_W + Sy; \beta_{YM} \ln Y \ln P_M + \\ &\beta_{KW} \ln K \ln P_W + \beta_{KM} \ln K \ln P_M + \beta_{MW} \ln P_M \ln P_W + Sy; \\ &\beta_{YK} \ln Y \ln K + U_i + \varepsilon \end{aligned}$$

where U is defined as the efficiency parameter. For simplicity, we omitted the time subscripts from the regression equations. U is the random inefficiency term, defined in Equation 2.

Equation 2:

$$\begin{aligned} U_i &= \frac{1}{2} \beta_{ITT} IT^2 + \beta_{IT} IT + \beta_{ITW} IT \ln P_W + \beta_{ITM} IT \ln P_M \\ &+ Sy; \beta_{ITY} IT \ln Y + \beta_{ITK} IT \ln K + \varepsilon_{IT} \end{aligned}$$

where ε_{IT} is independent from ε in the previous equation and $N(0,1)$ distributed. Substituting Equation 2 into Equation 1 and applying Shephard's lemma, we can derive the factor share equations of Equations 3a and 3b.

Equation 3a:

$$\begin{aligned} S_L = \frac{P_W L}{VC} &= \beta_W + \beta_{WW} \ln P_W + \beta_{MW} \ln P_M + Sy; \beta_{YW} \ln Y + \\ &\beta_{ITW} IT + \beta_{KW} \ln K \end{aligned}$$

Equation 3b:

$$\begin{aligned} S_M = \frac{P_M L}{VC} &= \beta_M + \beta_{MM} \ln P_M + \beta_{MW} \ln P_W + \sum_y \beta_{YM} \ln Y + \\ &\beta_{ITM} IT + \beta_{KM} \ln K \end{aligned}$$

with $S_L + S_M = 1w$

Because the shares must add to 1, the following parameter restrictions apply:

$$\begin{aligned} \beta_W + \beta_M &= 1 \\ \frac{1}{2} \beta_{WW} + \frac{1}{2} \beta_{MM} + \beta_{WM} &= 0 \\ \sum_y \beta_Y &= 0 \end{aligned}$$

Applying the preceding restrictions to Equations 1 through 3 produces the system of equations shown in Equation 4.

Equation 4:

$$\begin{aligned} \ln \frac{VC}{P_M} \alpha_0 + \beta_W \ln \frac{P_W}{P_M} + \sum_y \beta_Y \ln Y + \beta_K \ln K + \beta_{IT} IT + \frac{1}{2} \\ \beta_{WW} \ln^2 \frac{P_W}{P_M} + \frac{1}{2} \sum_y \beta_{YY} \ln^2 Y + \frac{1}{2} \beta_{ITT} IT^2 + \frac{1}{2} \beta_{KK} \\ \ln^2 K + \sum_y \beta_{YW} \ln Y \ln \frac{P_W}{P_M} + \beta_{ITW} IT \ln \frac{P_W}{P_M} + \\ \beta_{KW} \ln K \ln \frac{P_W}{P_M} + \sum_y \beta_{ITY} IT \ln Y + \beta_{ITK} IT \ln K + \sum_y \beta_{YK} \\ \ln Y \ln K + \varepsilon + \varepsilon_{IT} \end{aligned}$$

where both ε_{IT} and ε are $N(0,1)$ independent error terms. As the factor share equations sum to 1, we can omit one of them from the analysis while keeping only the labor share equation.

Equation 5:

$$\begin{aligned} S_L = \frac{P_W L}{VC} &= \beta_W + \beta_{WM} \ln \frac{P_W}{P_M} + \sum_y \beta_{YW} \ln Y + \beta_{ITW} IT + \\ &\beta_{KW} \ln K \end{aligned}$$

To correct for individual heterogeneity, we adjust Equation 4 with a set of qualitative variables, Z . These allow us to reduce heteroskedasticity within the data set.

Equation 6:

$$\begin{aligned} \ln \frac{VC}{P_M} &= \alpha_0 + \beta_W \ln \frac{P_W}{P_M} + \sum_Y \beta_Y \ln Y + \beta_K \ln K + \beta_{IT} \\ &IT + \frac{1}{2} \beta_{WW} \ln^2 \frac{P_W}{P_M} + \frac{1}{2} \sum_Y \beta_{YY} \ln^2 Y + \frac{1}{2} \beta_{ITT} IT^2 + \frac{1}{2} \beta_{KK} \\ &\ln^2 K + \sum_Y \beta_{YW} \ln Y \ln \frac{P_W}{P_M} + \beta_{ITW} IT \ln \frac{P_W}{P_M} + \beta_{KW} \\ &\ln K \ln \frac{P_W}{P_M} + \sum_Y \beta_{ITY} IT \ln Y + \beta_{ITK} IT \ln K + \sum_Y \beta_{YK} \ln Y \\ &\ln K + \sum_j \beta_j Z_j + \varepsilon + \varepsilon_{IT} \end{aligned}$$

Data and Estimation

In accordance with literature on the economics of IT and organizational productivity, this study generated a hospital production function using a six-year panel data set, transformed mathematically to be expressed in its cost form. (For example, the left-hand side of the equation represents costs while production is in the right-hand side of the equation.) The study models the production process by relating ordinary capital stock (K), labor (L), materials (M), and IT capital (IT) to hospital output (Y). The calculation of factor prices follows the conventional approach in this literature, including studies by M. D. Rosko in 2001 and by S. Zuckerman, J. Hadley, and L. Iezzoni in 1994.

Our approach to measuring IT capital is somewhat novel. The IT Capital Index is defined as:

$$IT_i = \frac{\sum_k P_k D_{ki}}{\sum_k P_k}$$

where $i = 1 \dots n$ represents the representative hospital, D_{ki} is an indicator variable taking the value of 1 if hospital i has application k , and P_k is the market price of application k , where $k = 1 \dots z$ is the total number of applications.

Our IT Capital Index then represents a hospital's IT value as a percentage of its total potential expenditure on IT. The presence (or absence) of each application is weighted by its price. We obtained price estimates for each application type in a representative 600-bed hospital—based on real price proposals from several software companies—and we adjusted these estimates for hospital size. This interpretation allows us to capture the effect of complexity among applications. We assume that more complex applications are relatively more expensive.

We define the rest of our variables more conventionally. Output is measured by adjusted patient days. According to Atkinson and Cockerill, adjusted patient days is a com-

bination of occupied bed days (inpatient data) and outpatient visits (outpatient data) where outpatient visits are adjusted based on the ratio of outpatient to inpatient revenue. Other variable definitions include the following:

- **Wage variable**—the wage index (wigrn) multiplied by the state's average wage rate
- **Operating expenses (Opex)**—defined as the sum of wages and material costs
- **Capital**—measured by revenue-adjusted bed size²
- **Labor**—measured by FTE hospital employees
- **Material costs**—include drugs and supplies charged
- **Controls**—include patient case mix, scope of services, ownership status, state, urban/rural, disproportionate share, teaching hospital, and medical school affiliation

Table A1 summarizes the data used in our analysis.

We used Zellner's seemingly unrelated regression (SUR) technique to simultaneously estimate Equations 4 and 5³ on page 39. Table A2 summarizes the regression results.

The coefficients of the state dummy variables are not reported. Dyear_i, i=2000...2004 are year dummies. Variables with an l extension represent their logarithmic transformation.

We tested the goodness of fit characteristics of the equations by Pearson Chi2 tests. As the test statistics are significant, we can accept that the estimated equations describe valid relationships. The Breusch-Pagan test of independence validates the use of a SUR approach, because its significance proves that the residuals in the two equations are correlated.

2. In our model, adjusting bed size by revenue produced more reasonable estimates of hospital capital, so we used this measure of capital. We tested the model using unadjusted bed size, and it produces no appreciable difference in the results.

3. Stochastic frontier analyses (SFA) were run from the data, and the results were not qualitatively different from those presented here.

Table A1: Summary Statistics for Input and Output Variables

Variable	Definition	Observations*	Mean	Std. dev.	Minimum	Maximum
Opex	Operating expenses	1,978	175453.2	11254.8	21023.25	1212469
IT	IT Capital Index	1,919	0.7879654	0.1318587	0.1621944	0.992844
Wage	Employee wages	1,978	61.65185	11.68129	37.60209	131.0122
Materials	Material costs	1,978	1.273089	1.007567	0.0019957	22.39164
Capital	Hospital bed size	1,919	264.6173	195.8513	15	2117.803
Adjpd	Adjusted patient days	1,978	103767.6	84791.41	112	907980
NFP	Not-for-profit hospital	1,978	0.7881699	0.4087084	0	1
Coth	Council of Teaching Hospitals	1,975	0.1124051	0.3159442	0	1
med_school	Medical school	1,975	0.3453165	0.4755918	0	1
Dispr	Disproportionate share hospital	1,978	0.3023256	0.4593817	0	1
servicescope	Scope of services available	1,874	40.84845	12.37864	0	73

*Minor variations in the number of observations values are a consequence of treatment of missing values by our statistical program.

The model results are theoretically validated by the variables taking their expected sign. The input variable wage has a positive coefficient in both equations, while quasi-fixed capital has a negative coefficient. Because the dependent variable is defined as operating cost per bed, the coefficient of capital must be adjusted by +1 and

hence it is -0.54. The output variable, ladjpd (adjusted patient days), also has the right sign, as its coefficient is positive. However, we should note that capital and adjusted patient days are highly correlated, and so their individual effects cannot be extracted from the analysis.

Table A2: SUR Analysis Results for IT Effects

	lopex equation (EQ 4)			SL equation (EQ 5)		
	Coefficient	Standard error	Level of significance	Coefficient	Standard error	Level of significance
Service scope	0.001908	-0.000268	1	0.001743	-0.000103	1
NPF	0.087104	-0.073302		0.065609	-0.002547	1
Dyear_2000	0.526620	-0.006611		-0.026780	-0.002561	1
Dyear_2001	0.376309	-0.006468		-0.018060	-0.002516	1
Dyear_2003	0.257706	-0.006367		-0.017570	-0.002478	1
Dyear_2004	0.517165	-0.006870		-0.041650	-0.002648	1
FP_IT	-0.229500	-0.081332	1			
IT	-0.970350	-0.545469	10	0.000461	-0.010665	
IT2	-0.690510	-0.318335	5			
ladjpdxIT	0.169824	-0.082808	5			
lwagexIT	-0.047470	-0.034932				
lcapitalxIT	-0.009790	-0.088253				
lwagexlcapital	-0.062690	-0.009001	1			
lwagexladjpd	-0.024060	-0.008198	1			
ladjpdxlcapital	0.006389	-0.017872				
lwage2	0.097341	-0.004517	1			
ladjpd2	0.081927	-0.016408	1			
lcapital2	0.128682	-0.023609	1			
ladjpd	-0.689060	-0.128102	1	0.016133	-0.003005	1
lwage	0.953385	-0.057360	1	0.154823	-0.001567	1
lcapital	-1.256150	-0.125756	1	-0.063130	-0.003346	1
coth	0.033843	-0.007869	1			
med_school	0.015697	-0.005155	1			
casemix	0.202493	-0.013209	1	0.038719	-0.004943	1
Large urban	-0.032670	-0.004628	1	-0.008500	-0.001784	1
dispr	-0.004400	-0.005556		-0.004690	-0.002153	5
Constant	9.807064	-0.634424	1			
RMSE	0.156573			0.173338		
# of observations	10,326			10,326		
Chi2	1.88E+07		1	93936.2		1

Breusch-Pagan test of independence: $Chi2(1) = 182.556$; significant at the 1% level.

The coefficients of the state dummy variables are not reported. $Dyear_i, i=2000...2004$ are year dummies. Variables with an l extension represent their logarithmic transformation.

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