Information Technology

Electronic Medical Records, Nurse Staffing, and Nurse-Sensitive Patient Outcomes: Evidence from California Hospitals, 1998–2007

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Objective. To estimate the effects of electronic medical records (EMR) implementation on medical-surgical acute unit costs, length of stay, nurse staffing levels, nursing skill mix, nurse cost per hour, and nurse-sensitive patient outcomes.

Data Sources. Data on EMR implementation came from the 1998–2007 HIMSS Analytics Databases. Data on nurse staffing and patient outcomes came from the 1998–2007 Annual Financial Disclosure Reports and Patient Discharge Databases of the California Office of Statewide Health Planning and Development (OSHDPD).

Methods. Longitudinal analysis of an unbalanced panel of 326 short-term, general acute care hospitals in California. Marginal effects estimated using fixed effects (within-hospital) OLS regression.

Principal Findings. EMR implementation was associated with 6–10 percent higher cost per discharge in medical-surgical acute units. EMR stage 2 increased registered nurse hours per patient day by 15–26 percent and reduced licensed vocational nurse cost per hour by 2–4 percent. EMR stage 3 was associated with 3–4 percent lower rates of in-hospital mortality for conditions.

Conclusions. Our results suggest that advanced EMR applications may increase hospital costs and nurse staffing levels, as well as increase complications and decrease mortality for some conditions. Contrary to expectation, we found no support for the proposition that EMR reduced length of stay or decreased the demand for nurses.

Key Words. Information technology in health, hospitals, nursing

Nurses play a key role in the acute care setting, and strong evidence suggests that higher levels of nurse staffing are associated with better patient outcomes (for reviews, see Lang et al. 2004; Kane et al. 2007; Thungjaroenkul, Cummings, and Embleton 2007; Unruh 2008). Nursing processes involve a

complex series of physical and cognitive activities (Potter et al. 2005). Research suggests that nurses spend 35 percent of nursing practice time on documentation and <20 percent of time on patient care activities (Hendrich et al. 2008). Lack of coordination among multidisciplinary teams of caregivers can create waste, inefficiencies, or delays in care. The complexity of workflow and the chance of errors have served as motivation for the use of health information technology (IT) to transform the work environment of nurses (Aspden et al. 2004). In theory, health IT might reduce the burden of nonvalue-added activities on nurses and lead to improvements in safety, quality, and satisfaction.

Given the importance of nurse staffing in patient safety and quality of care, the demand for qualified nurses is growing. Hospital turnover and vacancy rates are often high, and concerns about a nursing shortage have become a major policy issue (Berliner and Ginzberg 2003; Aiken 2008; Buchan and Aiken 2008). While policy makers have focused on increasing the number of nursing students, less attention has been given to improving the efficiency of the current nursing workforce. Some researchers have argued that IT may help address the nursing shortage by improving nurse efficiency (Kennedy 2003).

Health IT has the potential to reduce health care costs, improve efficiency, and enhance quality of care and patient safety (Blumenthal et al. 2008). One of the promising health IT applications is electronic medical records (EMR), which automates the paper-based patient chart and can improve clinical decisions. EMR can facilitate improvements to workflow, and its use in nurse-related hospital processes is an area of great promise and interest (Bolton, Gassert, and Cipriano 2008).

While interest in EMR adoption is high, little is known about the impacts of EMR on nurse staffing and patient outcomes in community hospital settings (Chaudhry et al. 2006; CBO 2008). This study examined the effects of EMR implementation on hospital costs, average length of stay (LOS), nurse staffing, and nurse-sensitive patient outcomes in California hospitals from 1998 to 2007.

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BACKGROUND

To understand the impact of EMR on hospital costs and patient outcomes, we developed a conceptual framework based on the structure, process, and outcome paradigm (Figure SA1). In our conceptualization, hospital management makes decisions about EMR (structure), which determine nursing workflow (process), and result in costs and quality of care (outcome). In our model, EMR directly impacts hospital costs (e.g., staffing efficiency, LOS) as well as quality (e.g., patient safety complications, in-hospital mortality). EMR may also play a mediating role in the effect of nurse staffing on patient outcomes.

EMR, Hospital Costs, and LOS

The business case for EMR investment includes projections of hospital cost savings from several sources, including reductions in LOS, reductions in the demand for nurses, reductions in redundant or inappropriate diagnostic tests and medications, and reductions in administrative expenses for medical records (Garrido et al. 2004; Giroi, Meili, and Scoville 2005).

Empirical studies have found a positive relationship between health IT investment and hospital financial performance (Menachemi et al. 2006; Thouin, Hoffman, and Ford 2008) and productivity (Menon, Lee, and Eldenberg 2000). While anecdotal reports suggest some cost savings from EMR (Hensing et al. 2008), evidence on the relationship between EMR and hospital costs is limited (Chaudhry et al. 2006).

EMR is projected to reduce inpatient LOS by reducing delays in the ordering process for services, streamlining discharge planning, and minimizing complications from preventable errors. Systematic reviews, however, have found mixed evidence that EMR can reduce LOS (Garg et al. 2005; Thompson, Classen, and Haug 2007). Garg et al. (2005) noted a difference in results where self-reported evaluations tended to report positive outcomes but independent evaluations did not. A recent study of 72 acute care hospitals found that clinical IT availability as measured through physician-reported automation scores was not significantly associated with lower LOS but was significantly associated with lower hospital costs (Amarasingham et al. 2009). Clinical IT in their study included automation of test results, notes and records, order entry, and decision support domains, which included EMR as one component. The lack of understanding about the effects of EMR on costs and LOS in community hospitals represents a critical gap in the literature.

H1: *EMR implementation is associated with lower hospital costs and LOS.**EMR and Nurse Staffing*

EMR can automate manual tasks, streamline documentation, and enhance communication among caregivers (Staggers, Weir, and Phansalkar 2008). In theory, savings in nurses' unproductive time can lead to reductions in staffing requirements or lower overtime (Case, Mowry, and Welebob 2002; Turisco and Rhoads 2008). EMR might also improve nurses' working conditions, which could lead to higher nurse satisfaction and lower turnover (Bolton, Gassert, and Cipriano 2008).

Evidence that EMR improves nurse efficiency is mixed. A systematic review found that bedside terminals and central station desktops reduced nurses' time spent on documentation by 24 percent (Poissant et al. 2005). However, surveys of nurses' perceptions and attitudes suggest that EMR may improve the quality of documentation but may not result in time savings due to increases in computer-related tasks (DesRoches et al. 2008; Kossman and Scheidenhelm 2008). Recent empirical studies on the effects of specific EMR applications on nurse time have not found significant time savings (Franklin et al. 2007; Asaro and Boxerman 2008; Hakes and Whittington 2008). One review projected that nurse time savings were not large enough to reduce staffing but could reduce overtime costs by U.S.\$11,000–33,000 annually for a large hospital (Thompson, Classen, and Haug 2007).

Whether and to what extent EMR reduces nurse staffing levels and nurse cost per hour remain open questions.

H2: *EMR implementation is associated with reductions in the demand for nurses.**EMR and Nurse-Sensitive Patient Outcomes*

EMR can improve the safety and quality of care through standardized care plans, guidelines and reminders, and automated alerts to prevent potential errors or adverse events (Anderson and Willson 2008; Staggers, Weir, and Phansalkar 2008). However, poor implementation, lack of integration, or incompatible systems may create workarounds and dissatisfaction, which can lead to errors and inefficiencies (Campbell et al. 2006; Harrison, Koppel, and Bar-Lev 2007).

Systematic reviews suggest that EMR can improve quality of care (Eslami, de Keizer, and Abu-Hanna 2008) and reduce the risk of medication errors (Shamliyan et al. 2008). However, some studies have found that com-

mercial systems increased rates of mortality (Han et al. 2005) and morbidity (Koppel et al. 2005).

Empirical studies on the relationship between EMR and nurse-sensitive patient outcomes have been inconclusive. A few studies have found significant correlations between clinical IT availability and better performance on patient safety indicators (PSI) (Featherly et al. 2007; Menachemi et al. 2007), risk-adjusted mortality, and complications (Amarasingham et al. 2009; Parente and McCullough 2009). However, other studies have not found significant associations between clinical IT availability and rates of patient safety complications (Culler et al. 2007) or in-hospital mortality for specific conditions (Menachemi et al. 2008).

To date, prior research has focused on self-developed systems at leading academic institutions, and little is known about the effects of EMR on patient outcomes in community hospitals (Chaudhry et al. 2006).

H3: *EMR implementation is associated with improvements in nurse-sensitive patient outcomes.*

METHODS

Data Sources

Data on EMR implementation came from the 1998–2007 HIMSS Analytics Databases. HIMSS Analytics annually surveys a sample of U.S. nonfederal hospitals affiliated with integrated health care delivery systems. The 2007 database included information on 5,066 hospital facilities (381 in California) and contained details on each hospital's adoption of EMR applications. Data on nurse staffing came from the 1998–2007 Annual Financial Disclosure Reports of the California Office of Statewide Health Planning and Development (OSHPD). OSHPD required acute care hospitals to annually submit a Financial Report, which contains information on costs, nurse staffing, discharges, and patient days by hospital unit. Data on nurse-sensitive patient outcomes came from the public version of the 1998–2007 OSHPD Patient Discharge Databases, which included information on patient risk factors, diagnosis codes, and in-hospital mortality.

Sample

The sample included medical–surgical acute units within short-term, general acute care hospitals in California. We excluded federal government, specialty,

children's, and long-term acute hospitals. We excluded Financial Reports that were not based on 365 days of reported data. The analytical dataset was an unbalanced panel of 326 hospitals and comprised 2,828 hospital-year observations.

EMR Implementation

We relied on expert opinion to create measures of EMR sophistication. Based on the HIMSS EMR Adoption Model (Garets and Davis 2006), we grouped EMR applications into three categories representing “stage of EMR implementation” (Table SA1). Hospitals at “EMR stage 1” (EMR-S1) have started implementation of the three core ancillary department information systems—pharmacy, laboratory, and radiology—and a clinical data repository. EMR-S1 functionality is characterized by automation of the patient record, facilitating communication within and between departments, and improving access to clinical information. Hospitals at “EMR stage 2” (EMR-S2) have implemented all EMR-S1 applications and have started implementation of Nursing Documentation (DOC) and Electronic Medication Administration Records. EMR-S2 functionality is characterized by automation of nursing workflow processes, including clinical documentation and electronic recording of medication administration. Hospitals at “EMR stage 3” (EMR-S3) have implemented all EMR-S1 and EMR-S2 applications and have started implementation of Clinical Decision Support (CDS) and Computerized Physician Order Entry (CPOE). EMR-S3 functionality is characterized by automation of clinical decision processes, including order entry management and support of clinical decision making. Our classification of EMR stages is similar to the taxonomy developed by a consensus panel of experts (Jha et al. 2009) in which HIT refers to the general term, and EMR (or EHR—Electronic Health Records) is one type of HIT that is further classified into three categories based on the sophistication and completeness of such relevant applications as DOC, CDS, and CPOE.

The HIMSS Analytics Database reported the year of contract date for each application and the current year's automation status (i.e., Automated/Live and Operational). Because we could not observe the actual start date of EMR implementation, we assumed that implementation began, on average, 1 year after the contract date. For observations where the contract date was missing, we used the earliest reported year where the application's status was Automated/Live and Operational.

We measured the effect of EMR based on the implementation start date rather than the Live and Operational date for several reasons. First, we believed that process changes were likely to occur during the early phases of implementation, and we wanted to capture these workflow-related changes to business processes during this initial period. Second, EMR may become Live and Operational on a pilot basis rather than hospital-wide, and we were unable to determine when EMR became Live and Operational in each hospital's medical-surgical acute units. If there were measurement errors in the contract date, this would bias against finding any effects of EMR. Thus, our measure of EMR implementation is relatively conservative and would underestimate the effect of EMR on costs, staffing, and outcomes.

We estimated the effect of EMR implementation for each EMR stage. Because EMR implementation is an incremental process spanning several years, we allowed the effect of EMR to vary over the first 3 years since the implementation started (i.e., year 1, year 2, and year 3).

Medical-Surgical Acute Unit Costs and LOS

We used the total direct cost, total discharges, and total patient days for the medical-surgical acute unit and created measures of cost per discharge, cost per patient day, and LOS. For cost per discharge, we divided total direct costs by total discharges. For cost per day, we divided total direct costs by total patient days. For LOS, we divided total patient days by total discharges.

Nursing Hours per Patient Day (HPPD), Nursing Skill Mix, and Nurse Cost per Hour

We specified measures of nursing HPPD, nursing skill mix, and nurse cost per hour. For nursing HPPD, we divided total productive hours by total patient days. We created separate variables for total nursing and for registered nurses (RN), licensed vocational nurses (LVN), and aides/orderlies (AID).

For nursing skill mix, we divided productive hours for each nurse type by total productive hours. We assumed that all Registry productive hours were for RNs. We created separate variables for RN percent, LVN percent, AID percent, and Registry percent.

For nurse cost per hour, we divided total salaries cost by total productive hours. This measure of cost per hour included the average hourly wage plus overtime. We created separate variables for RN cost per hour, LVN cost per hour, and AID cost per hour. For Registry cost per hour, we divided total contracted costs by total productive hours.

Nurse-Sensitive Patient Outcomes

We created measures of patient outcomes using the PSI and inpatient quality indicators (IQI) from the Agency for Healthcare Research and Quality. We applied the PSI and ISI software to the patient discharge data to calculate a hospital-level risk-adjusted rate per 1,000 hospitalizations for each PSI and IQI indicator. Using all of the PSI and IQI indicators with equal weights, we created composite scores for rates of patient safety complications, in-hospital mortality for conditions, and in-hospital mortality for procedures. These standardized composite scores were defined as the ratio of observed to expected outcomes.

We also created variables for specific patient outcomes known to be associated with nursing care (Needleman, Kurtzman, and Kizer 2007). These variables included hospital rates of decubitus ulcer, failure to rescue, infections due to medical care, acute myocardial infarction (AMI) mortality, congestive heart failure mortality, and pneumonia mortality.

Descriptive statistics for all dependent variables by year are reported in Table SA2.

Outliers

We found a small number of implausible values for unit costs, productive hours, discharges, and days. To minimize potential bias from data error, we trimmed the top and bottom 1 percent from the distributions of variables created from these measures.

Longitudinal Analysis

The longitudinal analysis specified fixed-effects regressions estimated by ordinary least squares. These regressions estimated the within-hospital effect of EMR implementation associated with changes in staffing and outcomes at the same facility. The strength of fixed-effects is the ability to control for confounding factors that vary across hospitals but are constant over time.

All regressions included control variables for staffed beds, case mix index, a quadratic time trend, and estimated robust standard errors. We took the natural logarithm of all dependent variables (except nursing skill mix) and reported marginal effects, which can be interpreted as the percent change in the dependent variable associated with EMR implementation.

Descriptive statistics for hospital characteristics by year are reported in Table SA3.

RESULTS

EMR Implementation in California Hospitals

EMR implementation increased significantly from 1998 to 2007, with rapid diffusion after 2003 (Figure 1). In 1998, only 33.9 percent of hospitals reported having started implementation of EMR, with nearly all facilities still at EMR-S1. By 2007, 80.8 percent of hospitals had begun EMR implementation at various stages, with 26.7 percent implementing EMR-S1, 21.5 percent implementing EMR-S2, and 32.6 percent implementing EMR-S3. Only 5.6 percent of hospitals had achieved EMR-S3 with an automation status of Live and Operational in 2007.¹

Effect of EMR Implementation on Hospital Costs and LOS

EMR-S2 and EMR-S3 were associated with 5.9–10.3 percent higher cost per discharge (Table 1). Higher costs were due to both higher cost per patient day and higher LOS. EMR-S3 increased cost per patient day by 5.0–9.6 percent and increased LOS by 3.7–4.4 percent. EMR-S1 was associated with 2.1 percent higher LOS in year 1 of implementation.

Figure 1: Electronic Medical Records (EMR) Implementation in California Hospitals: By Stage of EMR Sophistication

Table 1: Effect of Electronic Medical Records Implementation on Medical–Surgical Acute Unit Costs, Average Length of Stay, and Nurse Staffing Hours per Patient Day

	EMR Stage 1			EMR Stage 2			EMR Stage 3		
	Implementation Year			Implementation Year			Implementation Year		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Unit costs and average length of stay									
Cost per discharge	– 0.006 [0.018]	0.002 [0.017]	0.015 [0.016]	0.019 [0.026]	0.029 [0.024]	0.059** [0.023]	0.075*** [0.029]	0.103*** [0.029]	0.100*** [0.030]
Cost per patient day	– 0.019 [0.015]	– 0.002 [0.015]	0.016 [0.014]	0.029 [0.022]	0.042* [0.021]	0.069*** [0.021]	0.050* [0.026]	0.085*** [0.026]	0.096*** [0.029]
Average length of stay	0.021* [0.013]	0.013 [0.011]	0.010 [0.011]	0.015 [0.016]	0.010 [0.015]	0.009 [0.014]	0.044*** [0.017]	0.037** [0.019]	0.021 [0.020]
Nurse staffing hours per patient day (HPPD)									
Total nursing HPPD	0.000 [0.024]	0.146*** [0.040]	0.133*** [0.035]	0.112*** [0.042]	0.216*** [0.055]	0.199*** [0.048]	0.040 [0.030]	0.194*** [0.043]	0.160*** [0.040]
RN HPPD	– 0.008 [0.031]	0.154*** [0.051]	0.143*** [0.044]	0.146*** [0.062]	0.258*** [0.075]	0.242*** [0.065]	0.051 [0.040]	0.222*** [0.056]	0.187*** [0.054]
LVN HPPD	0.038 [0.099]	0.107 [0.101]	0.044 [0.099]	0.006 [0.136]	0.057 [0.130]	– 0.019 [0.123]	– 0.145 [0.140]	– 0.115 [0.168]	– 0.152 [0.190]
AID HPPD	0.086 [0.053]	0.200*** [0.055]	0.210*** [0.052]	0.137* [0.073]	0.221*** [0.074]	0.222*** [0.072]	0.148* [0.081]	0.294*** [0.088]	0.305*** [0.097]

Notes. Marginal effects from fixed effects (within-hospital) OLS regressions, adjusted for staffed beds, case mix index, and quadratic time trend. Robust standard errors in parentheses; significant at
*** $p < .01$,
** $p < .05$,
* $p < .10$.

Effect of EMR Implementation on Nursing HPPD

All three stages of EMR implementation increased nurse staffing levels (Table 1). Total nursing hours increased 13.3–14.6 percent with EMR-S1, 11.2–21.6 percent with EMR-S2, and 16.0–19.4 percent with EMR-S3. The increase in total HPPD was due to higher staffing levels for RNs and aides. RN staffing increased 14.3–15.4 percent with EMR-S1, 14.6–25.8 percent with EMR-S2, and 18.7–22.2 percent with EMR-S3. Aide staffing increased by 20.0–21.0 percent with EMR-S1, 13.7–22.2 percent with EMR-S2, and 14.8–30.5 percent with EMR-S3.

Effect of EMR Implementation on Nursing Skill Mix

We found little evidence for the relationship between EMR implementation and nursing skill mix (Table 2). EMR-S3 was associated with 1.9–2.3 percent lower Registry percent during years 2–3 of implementation. EMR-S1 and EMR-S2 were not associated with any significant changes in nursing skill mix.

Effect of EMR Implementation on Nurse Cost per Hour

In general, EMR implementation decreased nurse cost per hour (Table 2). EMR-S1 decreased RN cost per hour by 1.8 percent in year 2, decreased LVN cost per hour by 3.2–4.5 percent, decreased AID cost per hour by 1.7–2.6 percent, and decreased Registry cost per hour by 5.1 percent in year 1 of implementation. EMR-S2 decreased LVN cost per hour by 2.1–4.3 percent. EMR-S3 decreased LVN cost per hour by 3.7–4.5 percent in years 1–2 and decreased Registry cost per hour by 8.4 percent in year 1 of implementation.

Effect of EMR Implementation on Nurse-Sensitive Patient Outcomes

We found evidence that EMR implementation had a significant effect on nurse-sensitive patient outcomes (Table 3). EMR-S1 was associated with a 1.4–1.7 percent higher rate of complications in years 2–3 of implementation. However, we found no relationship between EMR-S1 and rates of in-hospital mortality or specific complications. EMR-S2 had little impact on patient outcomes. The only significant effect was a 16.7–16.9 percent lower rate of AMI mortality in years 2–3 of implementation. EMR-S3 was associated with higher rates of complications but lower rates of mortality. EMR-S3 increased complications by 2.3–3.0 percent in years 2–3 and decreased mortality for conditions by 3.0–4.2 percent.

Table 2: Effect of Electronic Medical Records (EMR) Implementation on Nursing Skill Mix and Nurse Cost per Hour

	EMR Stage 1			EMR Stage 2			EMR Stage 3		
	Implementation Year			Implementation Year			Implementation Year		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Nursing skill mix									
RN percent	−0.011 [0.009]	−0.008 [0.009]	−0.007 [0.009]	0.007 [0.014]	0.010 [0.013]	0.011 [0.013]	0.004 [0.013]	0.009 [0.014]	0.008 [0.015]
LVN percent	0.002 [0.007]	−0.005 [0.007]	−0.005 [0.006]	−0.006 [0.010]	−0.010 [0.010]	−0.009 [0.009]	0.000 [0.009]	−0.011 [0.010]	−0.013 [0.010]
AID percent	0.009 [0.007]	0.012 [0.008]	0.013 [0.009]	−0.001 [0.011]	−0.001 [0.011]	−0.003 [0.011]	−0.004 [0.012]	0.003 [0.013]	0.006 [0.014]
Registry percent	0.009 [0.007]	−0.005 [0.007]	−0.002 [0.006]	0.000 [0.009]	−0.015 [0.010]	−0.013 [0.009]	0.000 [0.009]	−0.019* [0.010]	−0.023*** [0.010]
Nurse cost per hour									
RN cost per hour	−0.015 [0.010]	−0.018** [0.009]	−0.008 [0.008]	−0.006 [0.014]	0.002 [0.012]	0.011 [0.012]	0.005 [0.015]	−0.001 [0.015]	0.010 [0.017]
LVN cost per hour	−0.039*** [0.012]	−0.045*** [0.010]	−0.032*** [0.010]	−0.043*** [0.016]	−0.032*** [0.013]	−0.021* [0.012]	−0.037*** [0.018]	−0.045*** [0.016]	−0.024 [0.018]
AID cost per hour	−0.017* [0.010]	−0.026*** [0.010]	−0.017* [0.010]	−0.011 [0.014]	−0.006 [0.013]	0.004 [0.013]	0.008 [0.016]	−0.005 [0.015]	0.011 [0.017]
Registry cost per hour	−0.051** [0.025]	−0.005 [0.026]	0.013 [0.023]	−0.031 [0.029]	−0.004 [0.030]	0.005 [0.029]	−0.084*** [0.033]	−0.025 [0.036]	0.004 [0.037]

Notes. Marginal effects from fixed effects (within-hospital) OLS regressions, adjusted for staffed beds, case mix index, and quadratic time trend. Robust standard errors in parentheses; significant at

*** $p < .01$,

** $p < .05$,

* $p < .10$.

Table 3: Effect of Electronic Medical Records (EMR) Implementation on Nurse-Sensitive Patient Outcomes

	EMR Stage 1			EMR Stage 2			EMR Stage 3		
	Implementation Year			Implementation Year			Implementation Year		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
In-hospital complications									
Patient safety indicators	0.011 [0.008]	0.014* [0.008]	0.017*** [0.008]	0.007 [0.011]	0.012 [0.011]	0.015 [0.010]	0.018 [0.012]	0.023* [0.012]	0.030*** [0.013]
Decubitus ulcer	0.074 [0.045]	0.052 [0.042]	0.031 [0.040]	-0.002 [0.064]	-0.007 [0.058]	-0.011 [0.055]	0.055 [0.068]	0.012 [0.066]	-0.031 [0.069]
Failure to rescue	-0.031 [0.109]	0.070 [0.115]	0.087 [0.102]	-0.174 [0.165]	-0.068 [0.142]	-0.015 [0.127]	0.003 [0.154]	0.100 [0.148]	0.160 [0.157]
Selected infections due to medical care	-0.027 [0.036]	-0.010 [0.033]	0.037 [0.032]	-0.037 [0.049]	-0.005 [0.044]	0.059 [0.041]	0.012 [0.054]	0.037 [0.052]	0.090 [0.056]
In-hospital mortality									
Mortality for procedures	0.004 [0.010]	0.010 [0.009]	0.011 [0.009]	-0.007 [0.014]	-0.001 [0.013]	0.003 [0.012]	-0.018 [0.015]	-0.021 [0.016]	-0.016 [0.016]
Mortality for conditions	0.013 [0.009]	0.012 [0.008]	0.008 [0.009]	0.002 [0.012]	-0.006 [0.011]	-0.018 [0.011]	-0.030*** [0.014]	-0.034*** [0.014]	-0.042*** [0.015]
AMI mortality	-0.043 [0.083]	-0.068 [0.071]	-0.066 [0.067]	-0.098 [0.097]	-0.167* [0.097]	-0.169* [0.098]	-0.037 [0.106]	0.033 [0.101]	0.058 [0.103]
CHF mortality	-0.033 [0.072]	0.025 [0.073]	0.028 [0.064]	-0.044 [0.109]	0.040 [0.099]	0.044 [0.093]	-0.107 [0.104]	-0.028 [0.114]	-0.064 [0.129]
Pneumonia mortality	-0.054 [0.053]	0.005 [0.054]	0.035 [0.052]	-0.037 [0.078]	-0.025 [0.078]	0.005 [0.070]	-0.110 [0.084]	-0.053 [0.101]	-0.030 [0.114]

Notes: Marginal effects from fixed effects (within-hospital) OLS regressions, adjusted for staffed beds, case mix index, and quadratic time trend. Robust standard errors in parentheses; significant at

*** $p < .01$,
** $p < .05$,
* $p < .10$.

DISCUSSION

This study examined the relationships between EMR implementation and hospital costs and LOS, nurse staffing, and nurse-sensitive patient outcomes in medical–surgical acute units of California hospitals. Little research has examined the impacts of EMR in community hospitals. Moreover, most prior studies have been cross sectional in design or focused on specific applications. To our knowledge, this study is the first to estimate the effect of EMR on costs and quality using longitudinal analyses at the unit level.

We found no support for the hypothesis that EMR is associated with lower hospital costs and LOS (H1). On the contrary, EMR-S3 resulted in higher cost per patient day and higher LOS. We found partial support for the hypothesis that EMR reduces the demand for nurses (H2). EMR-S2 reduced LVN cost per hour but increased RN staffing. Partial support was also found for the hypothesis that EMR is associated with improvements in nurse-sensitive patient outcomes (H3). EMR-S3 decreased the rate of mortality for conditions but increased the rate of complications.

Several explanations may account for these findings. The finding that EMR did not decrease LOS suggests that case-based payment incentives may have already exploited opportunities to reduce LOS or that per diem payment may work against reductions in LOS. The finding that EMR did not improve PSI could reflect EMR's ability to document the presence of more complications (Tang et al. 2007), which would bias against finding improvements in patient safety.

The association of EMR with increased staffing and a decline in patient safety may also reflect the unintended consequences of poor implementation or cultural resistance to change (Harrison, Koppel, and Bar-Lev 2007). Ineffective training and lack of coordination between physicians and nurses may lead to operational failures (Tucker and Spear 2006) or workarounds (Ash et al. 2007; Koppel et al. 2008), which could create staffing inefficiencies and increase the risk of complications or death (Sittig et al. 2006).

While EMR adoption by U.S. hospitals has been relatively slow (Furukawa et al. 2008), California experienced rapid diffusion of EMR beginning in 2003. One explanation for this sharp increase is the medication safety regulation passed in 2001 (Spurlock et al. 2003). Senate Bill 1875 required hospitals to submit their plans for using technological solutions to reduce medication errors by January 1, 2002. Most hospitals reported plans to adopt multiple technology tools, including EMR functionality, and implementation was expected by January 1, 2005.

Implications for Policy and Practice

Our study has implications for the policy debate over the benefits of health IT. The oft-cited, industry-sponsored RAND study's projection of U.S.\$31.2 billion in annual cost savings to hospitals was based on assumptions that EMR can reduce LOS and reduce nurses' unproductive time.² In fact, savings from reductions in LOS accounted for 62 percent and savings from reductions in nurse staffing accounted for 23 percent of RAND's estimate (Giroso, Meili, and Scoville 2005). We did not find evidence consistent with the projections of the RAND study, which raises concern about EMR's potential for cost savings to hospitals, at least in the short run.

Our findings also have important implications for practice. First, EMR may enhance the ability of hospitals to recruit and retain nurses. We found that EMR-S3 was associated with lower Registry percent, which is consistent with anecdotal reports that EMR can reduce reliance on agency nurses (Davis 2007). Second, EMR may reduce overtime. We found that all EMR stages reduced LVN cost per hour. This finding is consistent with anecdotal reports that EMR can reduce overtime (Hensing et al. 2008). Third, EMR may increase the demand for higher skilled nurses. We found that all EMR stages increased RN staffing, which is consistent with the theory that technology creates a skill-bias toward higher skilled workers (Schumacher 2002).

Our findings suggest that EMR may have implications for the nursing shortage. Prior research suggests that staffing levels are sensitive to the local supply of nurses (Blegen, Vaughn, and Vojir 2008). If EMR enables some hospitals to recruit and retain skilled nurses, this might widen disparities in nurse labor markets and potentially exacerbate the nursing shortage at non-EMR facilities.

Limitations

Our study has some limitations. First, the effect of EMR implementation may be biased from endogeneity and measurement error. While our fixed effects specification controls for differences across hospitals, our estimates may remain biased by the presence of time-varying unobservables that occurred concurrently with EMR. Potential confounders include organizational innovations, such as quality improvement initiatives (Weiner et al. 2006) and care delivery models (Tiedeman and Lookinland 2004), that might impact staffing or patient outcomes apart from the effects of EMR. Another potential confounder is California's minimum nurse staffing regulation, which mandated staffing ratios for medical-surgical acute units in 2004 and 2005 (Spetz 2004).

Staffing regulation increased RN hours but did not significantly improve nurse-sensitive patient outcomes (Donaldson et al. 2005; Bolton et al. 2007; Spetz et al. 2009). We tested the sensitivity of our results to alternative specifications that accounted for the introduction of staffing regulation. First, we included a dummy variable for years 2004–2007 to allow a shift in outcomes concurrent with the regulation. Second, we ran identical regressions on the preregulation period 1998–2003. The findings based on these approaches were qualitatively similar, and our conclusions were unchanged.

Second, the HIMSS Analytics Database is self-reported and primarily used in market research,³ which might lead to overestimates of actual rates of EMR implementation. Other national surveys have reported much lower adoption rates for EMR (see note 1). Because we were unable to observe the actual start date of EMR implementation and its usage, measurement error may bias our results.

Third, our findings may not be generalizable to all hospitals. We focused on short-term, general hospitals in California due to the availability and reliability of data sources. However, the experience of our sample may not be representative of other states and all types of hospitals.

Fourth, our study did not address related issues of importance. We were unable to examine the effect of EMR on nurse workload, nurse satisfaction, or turnover rates. We did not estimate the impact of EMR on patient utilization or expenditures, nor did we calculate the cost–benefit or return-on-investment from EMR implementation.

Finally, we focused on the short-term effects of EMR during the first 3 years of implementation, and we did not consider the long-term effects of EMR use over time. These issues are important subjects of future research.

CONCLUSION

We found that EMR implementation was associated with higher hospital costs and LOS, higher levels of nurse staffing, higher complications, and lower mortality for conditions. However, the effects varied by EMR stage and by year of implementation. In general, more advanced EMR (i.e., EMR-S3) had the largest effects on costs, staffing, and patient outcomes.

Our findings provide empirical evidence on the impact of EMR in community hospitals. The results imply that EMR may increase the demand for skilled nurses, which could have implications for nurse labor markets. Contrary to expectation, we found little support for the proposition that EMR

generates significant cost savings to hospitals through reductions in LOS and the demand for nurses.

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NOTES

1. We note that our estimates of EMR implementation represent the beginning of implementation in *any* unit of the hospital. A national survey reported that only 1.5 percent of hospitals have comprehensive EMR fully implemented in *all* hospital units (Jha et al., 2009). The same survey also reported that 27 percent of hospitals had begun implementation of CPOE and 11 percent had CPOE fully implemented in at least one unit.
2. The RAND study was a projection of *potential* savings from national adoption of comprehensive EMR based on a large number of assumptions (Hillestad et al. 2005). The study attempted to quantify efficiency savings based on assumptions derived from empirical studies in the literature (Giroi, Meili, and Scoville 2005). While often cited by policy makers, the study has been criticized for its failure to include studies with zero or negative savings (CBO 2008) and may not represent an estimate of *likely* savings due to EMR.
3. We note that the HIMSS Analytics Database is the only data source, to our knowledge, that conducts a longitudinal survey of EMR adoption in U.S. hospitals.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article:

Appendix SA1: Author Matrix.

Table SA1: Definition of Stage of EMR Implementation.

Table SA2: Descriptive Statistics for Dependent Variables, by Year.

Table SA3: Hospital Characteristics.

Figure SA1: Conceptual Framework for Electronic Medical Records, Nurse Staffing, and Performance.

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