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The Impact of Electronic Medical Records on Hospital-Acquired Adverse Safety Events: Differential Effects Between Single-Source and Multiple-Source Systems

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Abstract

The objective was to examine differential impacts between single-source and multiple-source electronic medical record (EMR) systems, as measured by number of vendor products, on hospital-acquired patient safety events. The data source was the 2009-2010 State Inpatient Databases of the Healthcare Cost and Utilization Project for California, New York, and Florida, and the Information Technology Supplement to the American Hospital Association's Annual Survey. Multivariable regression analyses were conducted to estimate the differential impacts of EMRs between single-source and multiple-source EMR systems on hospital-acquired patient safety events. In all, 1.98% of adult surgery hospitalizations had at least 1 hospital-acquired patient safety event. Basic EMRs with a single vendor or self-developed EMR systems were associated with a significant decrease in patient safety events by 0.38 percentage point, or 19.2%, whereas basic EMRs with multiple vendors had an insignificant association. A single-source EMR system enhances the impact of EMRs on reducing patient safety events.

Keywords

electronic medical records, electronic health records, medical errors, patient safety, inpatient care

Information technology (IT) is recognized as an innovation that can improve productivity across service industries.[1-3] The health care sector has struggled to improve quality and control costs.[4,5] Health information technologies (HITs) such as electronic medical records (EMRs) have the potential to improve the quality and outcomes of health care by innovating the process of health care delivery.[6] In particular, the adoption of HIT such as EMRs has the potential to improve patient safety and reduce medical errors.[7-10] Improving patient safety and reducing preventable medical errors have been national priorities since the Institute of Medicine published a report titled *To Err Is Human: Building a Safer Health System*.[7] EMRs are one proposed system-wide solution to reducing patient safety events by facilitating and coordinating the process of health care.[6,8-10]

To promote EMR adoption and align financial incentives, the 2009 Health Information Technology for Economics and Clinical Health Act established the Medicare and Medicaid Meaningful Use reward and incentive program. In 2011, the Centers for Medicare & Medicaid Services (CMS) implemented the reward and incentive program. Since its implementation, the incentive program has increased EMR adoption by hospitals. Between 2008 and 2012, the adoption rate of basic EMRs among general acute hospitals increased from 9% to 44%.[11,12]

Although the benefits of HIT are clear in theory and the adoption of EMRs has increased dramatically in response to the incentive program, there has been modest and mixed evidence that EMRs improve health care quality and outcomes.[6,13-23] Furthermore, it is not uncommon to find evidence that EMRs may lead to unintended consequences such as fostering new, unique safety risks and increasing the incidence of adverse patient safety events and medical errors.[24-26] The potential benefits accruing to an EMR investment are dependent in part on how well the various EMR components within a hospital interface

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with each other (intra-operability). Most prior studies fail to account for intra-operability when evaluating the impact of EMRs on health care quality and outcomes.

The purpose of this study is to examine to what extent the intra-operability of an EMR system, as measured by number of vendor products, affects the magnitude of EMR-associated changes in health care quality. In other words, this study does not examine how compatibility among EMR systems of different hospitals (interoperability) influences the ability to share patient health information with other hospitals (eg, health information exchange), but rather assesses to what extent compatibility of EMR system components within a hospital moderates potential EMR benefits. A large patient-level administrative data set from California, New York, and Florida for 2009 and 2010 was analyzed. Multivariable regression models with hospital-specific effects were used to account for potential confounders in observational data. This study contributes to the literature and federal HIT policy by examining whether appropriate EMR system designs influence the impact of EMRs on health care quality, as measured by hospital-acquired adverse patient safety events. The study's findings are of interest to policy makers, clinicians, and administrators designing and implementing an appropriate EMR system guaranteeing intra-operability, or compatibility of EMR system components, within hospitals.

Table 1. Types of Hospital-Acquired Patient Safety Events.[a]

1. Surgical Only safety events
Foreign body left in during procedure (AHRQ PSI 5)
Postoperative hemorrhage or hematoma (AHRQ PSI 9)
Postoperative wound dehiscence (AHRQ PSI 14)
Postoperative pulmonary embolism or deep vein thrombosis (AHRQ PSI 12)
Postoperative respiratory failure (AHRQ PSI 11)
Postoperative sepsis (AHRQ PSI 13)
Postoperative physiologic and metabolic derangements (AHRQ PSI 10)
Postoperative hip fracture (AHRQ PSI 8)
Death among surgical inpatient with serious treatable conditions (AHRQ PSI 4)
2. Likely procedure safety events
Accidental puncture or laceration during procedure (AHRQ PSI 15)
Iatrogenic pneumothorax (AHRQ PSI 6)
Infection due to medical care (AHRQ PSI 7)
3. Any inpatient safety events
Death in low mortality DRG (AHRQ PSI 2)
Pressure ulcer (AHRQ PSI 3)
Transfusion reaction (AHRQ PSI 16)

Abbreviations: AHRQ, Agency for Healthcare Research and Quality; DRG, diagnosis-related group; PSI, patient safety indicator.
[a]Hospital-acquired patient safety events are measured by 15 types of PSIs developed by AHRQ based on diagnosis codes (*International Classification of Diseases, Ninth Revision, Clinical Modification*) and present on admission flags.

Methods

Data Source and Sample

The study used 2 data sets. First, the source of patient outcome data is the 2009-2010 Healthcare Cost and Utilization Project State Inpatient Databases (HCUP SID) for California, New York, and Florida. HCUP SID is a hospital inpatient administrative database containing principal and secondary diagnoses/procedures, patient demographics, admission/discharge status, total charges, length of stay, and information on the primary payer for each hospital stay.[27]

Second, the source of EMR data is the Information Technology Supplement to the American Hospital Association's Annual Survey (AHA IT survey) for 2009 and 2010. The survey tracks the adoption of HIT including EMRs. The survey asks participants to report on the presence of clinical functionalities of their EMR system and the extent of implementation of these functionalities in clinical units. The survey also contains supplementary measures on features of EMR systems. For this study, the AHA IT survey was linked to the HCUP SID patient data for California, New York, and Florida.

The unit of observation in this study is any adult surgical patient admission at risk for at least 1 of the patient safety events measured by the 15 Agency for Healthcare Research and Quality's Patient Safety Indicators (AHRQ PSIs). This study focuses on surgical patients because surgical care involves complex and high-risk treatment, and during their hospital stay surgical patients are more likely to experience adverse patient safety events and medical errors than nonsurgical patients. Furthermore, a majority of AHRQ PSIs consist of surgery-related events (Table 1). Surgical patient discharges are identified using major surgery diagnosis-related groups embedded in the PSI software developed by AHRQ. The AHRQ PSI software defines the population of patients at risk (denominator) for each PSI. This study excludes any surgical patient discharges that are not at risk for any of the 15 PSIs. However, 98.3% of surgical patient discharges in the study sample are at risk for at least 1 of the 15 PSIs. The study sample consists of 2 479 717 hospitalizations from 444 hospitals. This study does not require institutional review board approval because the data set contains de-identified secondary data.

Measures

Hospital-Acquired Adverse Patient Safety Events. The primary outcome of this study is a composite measure of hospital-acquired adverse patient safety events as listed in Table 1. The adverse patient safety events are measured by 15 AHRQ PSIs based on diagnosis codes (*International Classification of Diseases, Ninth Revision, Clinical Modification*). Using present on admission (POA) flags for diagnosis codes, hospital-acquired PSI indicators are constructed. Following Houchens and colleagues and the HCUP Present on Admission Report, hospitals are eliminated if more than 99% of their secondary diagnoses were coded as POA, or more than 20% of POA flags for secondary diagnoses were missing.[28,29]

Key Explanatory Variables. The key explanatory variables are (1) basic EMR use and (2) a single-vendor/self-developed EMR. Single-vendor/self-developed EMR is a dichotomous measure recorded as positive if an EMR system has a single vendor, or if it is a self-developed EMR system. The measure is equal to zero if an EMR system has multiple vendors. Basic EMR use also is a dichotomous measure following the 3-level definition of EMR adoption developed by Jha and colleagues.[12] Basic EMR use is defined as having the following 8 functionalities in at least 1 major clinical unit: (1) patient demographic information, (2) patient problem lists, (3) medication lists, (4) discharge summaries, (5) laboratory reports viewer, (6) radiology reports viewer, (7) diagnostic test results viewer, and (8) computerized provider order entry (CPOE) for medications.

Statistical Analysis

To estimate heterogeneous EMR impacts between single-source and multiple-source EMR systems on hospital-acquired adverse patient safety events, this study uses multivariable regression analysis with an interaction term between basic EMR use and single-vendor/self-developed EMR use. The basic specification is the following:

$$\begin{aligned}\text{Patient Safety}_{ijt} = \alpha + \beta_1\left(\text{Basic EMRs}\right)_{jt} + \\ \beta_2\text{Single-vendor/self-developed} \\ \text{EMR}_{jt} + \beta_3\left(\text{Basic EMRs}\right)_{jt} * \\ \text{Single-vendor/self-developed} \\ \text{EMR}_{jt} + \beta_4 D_{jt} + \beta_5 P_{ijt} + \tau_t + \delta_j + \varepsilon_{ijt}\end{aligned} \tag{1}$$

Patient Safety for patient *i* in hospital *j* in year *t* is a binary indicator equal to one if a surgery admission has any adverse patient safety events during the hospitalization. *Basic EMRs* indicates whether the hospital adopted 8 basic EMR functionalities in at least 1 major clinical unit. *Single-vendor/self-developed EMR* also is a binary indicator equal to 1 if an EMR system has a single vendor or it is a self-developed EMR system. *D* is a vector of hospital characteristics (teaching status, hospital beds, ownership, number of surgical discharges) and area characteristics (urban, state fixed effect), and *P* is a vector of patient characteristics (age, sex, race/ethnicity, primary source of payment, median household income) and health status of patients (29 comorbidities). Year effects (τ_t) also are included.

EMR adoption and hospital-acquired patient safety events are potentially correlated with unobservable characteristics of hospitals. This would bias estimates of the impact of EMRs on patient safety events during hospitalization. To address this issue, this study includes hospital-specific effects (δ_j), which can be assumed to be random or fixed. Ordinary least squares (OLS), fixed effects (FE), and random effects (RE) models were estimated. The Hausman test is used to check the null hypothesis that hospital RE estimates are consistent, relative to hospital FE estimates.[30,31]

All of the regressions used the linear probability model. This model was chosen because this study uses interactions between basic EMRs and single-vendor/self-developed EMRs, and interaction terms are complex to interpret in nonlinear models, such as probit and logit.[32,33] In addition, as a robustness check, all equations were estimated using a logit model, and the results for all major variables were similar to those from the linear probability model. (The results for the robustness test are available from the authors upon request.) In all regressions, the standard errors are clustered at the hospital level to address the correlation across patient discharges within hospitals.

Results

Table 2 reports summary statistics for hospital-acquired patient safety events, basic EMR use, single-vendor/self-developed EMR, and other covariates. Column 1 presents the 2009-2010 sample while columns 2 and 3 contain summary statistics from the 2009 sample and the 2010 sample, respectively. In the 2009-2010 sample, 41.7% of adult surgery admissions are in hospitals with basic EMRs, and 1.98% of adult surgery hospitalizations had at least 1 hospital-acquired patient safety event. In the sample of 2010, adult surgery admissions are characterized with fewer hospital-acquired patient safety events, but more basic EMRs and intra-operable EMR systems with a single vendor or self-developed system, compared with the 2009 sample.

Table 3 reports the differential estimated associations of EMRs between single-source and multiple-source EMR systems with hospital-acquired adverse patient safety events using OLS, FE, and RE methods. Columns 1 to 3 indicate that estimates from the OLS, RE, and FE methods

Table 2. Summary Statistics.[a]

Variables	Sample of 2009-2010	Sample of 2009	Sample of 2010
Dependent/key independent variables			
Hospital-Acquired Patient Safety Events	0.0198	0.0208	0.0183
Basic Electronic Medical Record (EMR)	0.417	0.308	0.513
Single-vendor/self-developed EMR	0.674	0.597	0.760
Basic EMR & (Single-vendor/self-developed EMR)	0.323	0.237	0.400
Patient's characteristics			
Age	55.60 (19.50)	55.38 (19.60)	55.72 (19.44)
Female	0.605	0.608	0.605
Race/ethnicity			
White, non-Hispanic	0.619	0.624	0.612
Black, non-Hispanic	0.100	0.0960	0.106
Hispanic	0.178	0.173	0.184
Asian or Pacific Island, non-Hispanic	0.0414	0.0431	0.0387
Other race, non-Hispanic	0.0613	0.0636	0.0592
Primary source of payment			
Private insurance	0.374	0.381	0.364
Medicare	0.384	0.378	0.389
Medicaid	0.157	0.156	0.160
Other	0.0852	0.0847	0.0875
Median household income for patient's zip code			
First quartile	0.241	0.234	0.245
Second quartile	0.250	0.240	0.262
Third quartile	0.277	0.277	0.281
Fourth quartile	0.232	0.248	0.212
Patient's health status			
Chronic conditions			
AIDS	0.00126	0.00130	0.00128
Alcohol abuse	0.0215	0.0213	0.0223
Deficiency anemias	0.146	0.143	0.151
Rheumatoid arthritis/collagen vascular disease	0.0202	0.0197	0.0208
Chronic blood loss anemia	0.0302	0.0300	0.0306
Congestive heart failure	0.0394	0.0386	0.0404
Chronic pulmonary disease	0.134	0.130	0.137
Coagulopathy	0.0379	0.0354	0.0410
Depression	0.0672	0.0642	0.0707
Diabetes without chronic complications	0.155	0.153	0.158
Diabetes with chronic complications	0.0373	0.0354	0.0394
Drug abuse	0.0157	0.0152	0.0164
Hypertension	0.449	0.439	0.459
Hypothyroidism	0.0877	0.0853	0.0901
Liver disease	0.0200	0.0191	0.0208
Lymphoma	0.00466	0.00463	0.00460
Fluid and electrolyte disorders	0.129	0.125	0.135
Metastatic cancer	0.0247	0.0248	0.0244
Other neurological disorders	0.0388	0.0382	0.0397
Obesity	0.101	0.0967	0.106
Paralysis	0.0174	0.0170	0.0178
Peripheral vascular disease	0.0578	0.0555	0.0599
Psychoses	0.0211	0.0202	0.0225
Pulmonary circulation disease	0.0132	0.0125	0.0138
Renal failure	0.0781	0.0747	0.0815
Solid tumor without metastasis	0.0150	0.0149	0.0151
Peptic ulcer disease excluding bleeding	0.000359	0.000359	0.000366
Valvular disease	0.0281	0.0276	0.0283
Weight loss	0.0285	0.0264	0.0312
Hospital characteristics			
Hospital bed size	545.7 (460.4)	547.8 (496.1)	541.8 (422.7)
Number of surgical discharges (surgical volume)	8702.9 (7312.0)	8687.8 (7698.9)	8484.2 (6698.9)
Ownership			
Not for profit	0.730	0.724	0.723
For profit	0.0820	0.0788	0.0856
Public	0.188	0.197	0.191
Teaching hospital	0.523	0.517	0.518
Area characteristics			
Urban	0.538	0.529	0.549
California	0.413	0.435	0.392
New York	0.277	0.274	0.268
Florida	0.310	0.291	0.341
Year10	0.480		
Observations	2 479 717	1 289 244	1 103 124

[a]Standard deviations are in parentheses.

are similar. The FE model (column 3) excludes hospital characteristics (teaching status, hospital beds, ownership) and area characteristics (urban, state fixed effect) because there is little (or no) change in these covariates over the 2 study years. Basic EMRs with multiple vendors were not associated with a significant decrease in hospital-acquired patient safety events. However, the coefficients for the interaction term (Basic EMRs ∗ Single-vendor/self-developed EMR) were negative and statistically significant, and the magnitude of the coefficients on the interaction are greater than the magnitude of coefficients on Basic EMRs. This indicates that basic EMRs with a single vendor or self-developed EMR systems were associated with a significant decrease in the probability of patient safety events whereas basic EMRs with multiple vendors were not associated with a decrease in patient safety events during hospitalizations. The Hausman test suggests that FE, rather than RE, is the appropriate specification because it rejects the null hypothesis that hospital-specific effects are uncorrelated with the regressors and the difference between fixed effect and random effect estimators is not systematic. Specifically, in the FE regression, basic EMRs with a single-vendor or self-developed EMR systems were associated with a significant decrease in the probability of patient safety events by 0.38 percentage point, or 19.2%, whereas basic EMRs with multiple vendors had an insignificant association with patient safety events. For an average hospital in the study sample with 546 beds and 8703 annual surgical hospitalizations that has 172 hospital-acquired adverse patient safety events among surgical patients per year, a single-source EMR system leads to 33 fewer patient safety events—a 19.2% reduction.

Robustness tests are performed to address concerns that estimates on the interaction terms may capture individual

Table 3. Estimated Association of Electronic Medical Records (EMRs) and Intra-operability With Hospital-Acquired Patient Safety Events.[a]

Dependent Variable: Hospital-Acquired Patient Safety Events	Model (1): OLS[b]	Model (2): Random Effects[c]	Model (3): Fixed Effects[d]
Key independent variables			
Basic EMR	0.00287** (0.00105)	0.00171* (0.00077)	0.00206 (0.00147)
Single-vendor/self-developed EMR	0.00072 (0.00093)	0.00004 (0.00069)	0.00095 (0.00091)
Basic EMR & (single-vendor/self-developed EMR)	−0.00333** (0.00126)	−0.00256** (0.00093)	−0.00380** (0.00129)
Patient's characteristics			
Age group (Ref: Age 18-37)			
Age 38-53	0.00779** (0.00033)	0.00765** (0.00032)	0.00767** (0.00032)
Age 54-65	0.00998** (0.00047)	0.00995** (0.00046)	0.01000** (0.00046)
Age 66-75	0.01156** (0.00058)	0.01178** (0.00055)	0.01187** (0.00055)
Age 76 or older	0.01031** (0.00077)	0.01082** (0.00069)	0.01098** (0.00069)
Female	−0.00123** (0.00027)	−0.00103** (0.00026)	−0.00099** (0.00027)
Race/ethnicity (Ref: White, non-Hispanic)			
Black, non-Hispanic	0.00106* (0.00051)	0.00146** (0.00040)	0.00153** (0.00039)
Hispanic	0.00022 (0.00034)	0.00069* (0.00027)	0.00081** (0.00028)
Asian or Pacific Island, non-Hispanic	0.00048 (0.00063)	0.00100+ (0.00053)	0.00105* (0.00053)
Other Race, non-Hispanic	−0.00007 (0.00048)	0.00054 (0.00041)	0.00062 (0.00042)
Primary source of payment (Ref: Private insurance)			
Medicare	0.00016 (0.00039)	0.00018 (0.00037)	0.00022 (0.00037)
Medicaid	−0.00069* (0.00031)	−0.00063+ (0.00035)	−0.00063+ (0.00036)
Other	−0.00217** (0.00041)	−0.00203** (0.00040)	−0.00202** (0.00041)
Median household income for patient's zip code			
Second quartile	−0.00042 (0.00035)	−0.00031 (0.00030)	−0.00046 (0.00031)
Third quartile	−0.00026 (0.00042)	−0.00011 (0.00027)	−0.00031 (0.00027)
Fourth quartile	−0.00030 (0.00048)	−0.00052 (0.00033)	−0.00075* (0.00034)
Patient's health status			
Chronic conditions			
AIDS	−0.00509+ (0.00288)	−0.00523+ (0.00286)	−0.00524+ (0.00285)
Alcohol abuse	−0.00009 (0.00092)	−0.00012 (0.00090)	−0.00014 (0.00090)
Deficiency anemias	−0.00003 (0.00059)	0.00014 (0.00057)	0.00013 (0.00057)
Rheumatoid arthritis/collagen vascular disease	−0.00087 (0.00076)	−0.00112 (0.00077)	−0.00116 (0.00077)
Chronic blood loss anemia	−0.00110 (0.00071)	−0.00100 (0.00075)	−0.00097 (0.00075)
Congestive heart failure	0.01004** (0.00100)	0.01003** (0.00099)	0.00995** (0.00099)
Chronic pulmonary disease	0.00254** (0.00039)	0.00254** (0.00040)	0.00251** (0.00040)
Coagulopathy	0.04052** (0.00198)	0.04047** (0.00193)	0.04041** (0.00193)
Depression	−0.00129** (0.00046)	−0.00153** (0.00044)	−0.00158** (0.00044)
Diabetes without chronic complications	−0.00184** (0.00032)	−0.00193** (0.00031)	−0.00198** (0.00031)
Diabetes with chronic complications	−0.00958** (0.00064)	−0.00935** (0.00063)	−0.00932** (0.00064)
Drug abuse	0.00063 (0.00090)	0.00023 (0.00092)	0.00019 (0.00092)
Hypertension	−0.00326** (0.00041)	−0.00328** (0.00040)	−0.00328** (0.00040)
Hypothyroidism	−0.00173** (0.00042)	−0.00183** (0.00041)	−0.00184** (0.00041)
Liver disease	0.00832** (0.00137)	0.00777** (0.00134)	0.00772** (0.00134)
Lymphoma	−0.00433** (0.00155)	−0.00473** (0.00156)	−0.00483** (0.00156)
Fluid and electrolyte disorders	0.03211** (0.00118)	0.03214** (0.00117)	0.03219** (0.00117)
Metastatic cancer	0.01265** (0.00113)	0.01202** (0.00101)	0.01183** (0.00099)
Other neurological disorders	0.00375** (0.00082)	0.00371** (0.00080)	0.00367** (0.00080)
Obesity	0.00314** (0.00037)	0.00356** (0.00035)	0.00365** (0.00035)
Paralysis	0.01587** (0.00141)	0.01550** (0.00140)	0.01533** (0.00140)
Peripheral vascular disease	0.00665** (0.00080)	0.00667** (0.00078)	0.00666** (0.00077)
Psychoses	0.00182* (0.00081)	0.00195* (0.00080)	0.00196* (0.00079)
Pulmonary circulation disease	0.13923** (0.00493)	0.13874** (0.00491)	0.13865** (0.00490)
Renal failure	−0.00062 (0.00060)	−0.00062 (0.00059)	−0.00063 (0.00059)
Solid tumor without metastasis	0.00286** (0.00104)	0.00236* (0.00100)	0.00224* (0.00100)
Peptic ulcer disease excluding bleeding	0.01469* (0.00674)	0.01421* (0.00673)	0.01429* (0.00673)
Valvular disease	−0.01032** (0.00096)	−0.01036** (0.00095)	−0.01037** (0.00095)
Weight loss	0.05589** (0.00355)	0.05592** (0.00319)	0.05615** (0.00315)

(continued)

Table 3. (continued)

Dependent Variable: Hospital-Acquired Patient Safety Events	Model (1): OLS[b]	Model (2): Random Effects[c]	Model (3): Fixed Effects[d]
Hospital characteristics			
Hospital bed size (Ref: >300 beds)			
Small (<100 beds)	−0.00014 (0.00143)	0.00146 (0.00152)	
Medium (100-300 beds)	−0.00114 (0.00078)	−0.00049 (0.00070)	
Surgical volume (1000 surgical discharges)	0.00004 (0.00011)	0.00027** (0.00010)	0.00006 (0.00093)
Ownership: (Ref: Not for profit)			
For profit	−0.00079 (0.00080)	−0.00114 (0.00094)	
Public	0.00292** (0.00102)	0.00296** (0.00082)	
Teaching hospital	0.00403** (0.00095)	0.00179* (0.00077)	
Area characteristics			
Urban	0.00259** (0.00071)	0.00246** (0.00060)	
New York	−0.00102 (0.00078)	−0.00022 (0.00068)	
Florida	−0.00180+ (0.00094)	−0.00089 (0.00075)	
Year10	−0.00338** (0.00050)	−0.00307** (0.00036)	−0.00309** (0.00038)
Observations	2 479 717	2 479 717	2 479 717

[a]Standard errors are in parentheses.
[b]Model (1) is estimated with ordinary least square (OLS) regressions.
[c]Model (2) is estimated with hospital random effects.
[d]Model (3) is estimated with hospital fixed effects.
**Statistically significant at the 99% level. *Statistically significant at the 95% level. +Statistically significant at the 90% level.

effects of basic EMRs or single-vendor/self-developed EMRs on patient safety events. To ensure that the estimations are capturing interaction effects and not individual effects, this study estimates the impact of (1) basic EMRs only on patient safety events and (2) basic EMRs and single-vendor/self-developed EMRs without interactions on patient safety events. Appendix Table 1 (available with the online article) shows that the estimates on basic EMRs and single-vendor/self-developed EMRs are insignificant in all of these models, which supports the robustness of the interaction estimates in Table 3.

Discussion

This study estimates the differential association of EMRs between single-source and multiple-source EMR systems, as measured by number of vendor products, with hospital-acquired adverse patient safety events. This study finds that intra-operability or compatibility of an EMR system, proxied by single-source EMR systems, increases the impact of EMRs on reducing patient safety events. A basic EMR system with a single vendor or a self-developed EMR system was associated with a significant decrease in the rates of patient safety events of 19.2%.

Basic EMRs incorporate essential functionalities such as CPOE, which impact care processes and thus improve patient safety. However, there has been limited empirical evidence of EMR benefits on improving patient safety. One explanation for this phenomenon is that poor intra-operability could impact patient safety events. Therefore, the findings of this study confirm that to achieve EMR benefits in improving patient safety, an EMR needs not only to include essential functionalities, but also must guarantee intra-operability, or compatibility of EMR system components, within hospitals.

The theoretical framework of this study is built on an IT-enabled process innovation framework by Thomas H. Davenport.[2] According to Davenport's framework, IT improves the productivity and performance of organizations through process innovations. This study considers an EMR system as a tool to innovate processes of health care. The approach examining how an EMR system improves health care quality and outcomes through process innovation is consistent with previous HIT studies by Dranove et al and McCullough et al.[19,20]

The compatibility of an IT system plays a role in facilitating IT process innovation. Specifically, a more compatible IT system may promote process innovation related to IT by ensuring better communication and coordination.[34-36] As Silow-Carrol et al find in their Commonwealth Fund study, IT systems facilitate patient safety and quality improvement through the use of checklists, alerts, and predictive tools; embedded clinical guidelines that promote standardized, evidence-based practices; electronic prescribing and test ordering that reduces errors and redundancy; and discrete data fields that foster use of performance dashboards and compliance reports. Quicker, more accurate communication, and streamlined processes, the authors determine, lead to improved patient flow, fewer duplicative test, and faster responses to patient inquires.[37] Moreover, studies show that these IT benefits have a significant positive influence on surgical patients as well.[38,39]

Consequently, this study concludes that there are likely to be implementation advantages for hospitals purchasing additional IT component products from a single vendor, or hardware and software that is compatible with their existing IT system and products. Intra-operability or compatibility of EMR systems, proxied by single-source EMR systems, appears to have moderating effects that strengthen the EMR's benefits in reducing adverse patient safety events and medical errors because better connectivity of EMR systems within hospitals may enhance the effectiveness of the system. In contrast, with multiple-source EMR systems from multiple vendors operating across various clinical units, it is difficult to transfer, exchange, and integrate patient information among different clinicians caring for the same patients, which attenuates the effectiveness of the system. Thus, multiple-source EMR systems with different vendors in which intra-operability, or compatibility, is not guaranteed may fail to achieve the full potential of EMR benefits in reducing patient safety.

This finding contributes to the HIT literature by providing robust empirical evidence with a large, patient-level administrative data set that intra-operability, or compatibility, of an EMR system promotes the benefits of the EMR in improving health care quality. This study also complements recent EMR studies on improving patient safety.[13,15,18,22,23,40] Although this study found that EMRs were not associated with reducing patient safety events on average, a single-source basic EMR system was associated with a significant reduction in patient safety events. It also is important to note that this study establishes generalizable measures for patient safety events during hospitalization using 15 types of AHRQ PSIs and POA indicators.

Endogeneity between EMRs and patient safety events could potentially bias the impact of EMRs on patient safety events in both directions. For instance, if high-quality hospitals with low patient safety events tend to adopt EMRs, simple OLS would overestimate the impact of EMRs on patient safety events. On the other hand, if hospitals with high-risk patients are more likely to adopt EMRs, simple OLS would underestimate the impacts of EMRs on patient safety events. To address this issue, this study estimated hospital RE and FE models. The Hausman test suggested that FE models were appropriate to use instead of RE models, consequently rejecting the assumption that the unobserved hospital characteristics are uncorrelated with observables. This aligns with conventional wisdom that characteristics of a hospital and patients in that hospital are correlated. However, differences in the point estimates are small, indicating that the bias resulting from failure to account for endogenous EMR adoption is modest in the sample.

This study has several limitations. First, nonresponse would have biased the estimates given that only 61.7% of adult surgical admissions in California, New York, and Florida during 2009-2010 are linked to the AHA IT survey because of survey nonresponse. Second, information on the diversity and complexity of EMR systems and functionalities used in hospitals in the AHA IT survey was limited. Thus, this study did not capture the impact of unobserved features of EMR systems, such as data architecture and end-user interface in different clinical units on patient safety events. Third, although the regressions include a rich set of covariates, the authors were not able to capture all relevant patient and hospital characteristics, and these unobservable characteristics confounded the impact of EMR on patient safety events. However, FE and RE models allowed for the examination of whether unobserved characteristics confounded the impact of EMR on patient safety events, and the estimates remained robust.

Conclusion

This study's findings address important interest areas for policy makers promoting EMR Meaningful Use and clinicians. EMRs with appropriate systems guaranteeing compatibility and intra-operability are essential to achieving the benefits of EMRs on improving health care quality and outcomes. However, while the CMS EMR incentive program emphasizes the interoperability of EMR systems, and its meaningful use requirement includes the ability to exchange clinical information across hospitals and health systems, intra-operability of EMR systems within hospitals is not addressed. Therefore, the results of this study suggest that CMS and policy makers also should consider the compatibility of EMR systems as a meaningful use component to guarantee the intra-operability of EMR systems within hospitals.

This study also makes several contributions to the literature. First, it analyzes a large, patient-level administrative data set to estimate the impact of intra-operability of EMR system components within a hospital on patient safety. Second, generalizable measures are used for both patient safety events (15 types of AHRQ PSIs) and EMR use (basic EMRs consisting of 8 functionalities). This study also improves measures of patient safety events by distinguishing between adverse patient safety events that occurred during hospitalization with those POA. The specific method used to identify hospital-acquired patient safety events is described in more detail in the Hospital-Acquired Adverse Patient Safety Events section. Finally, the endogenous adoption of EMRs is addressed by employing hospital RE and FE models.

A single-source EMR system enhances the impact of EMRs on reducing patient safety events. The successful use of EMRs requires appropriate EMR systems that guarantee the intra-operability, or compatibility, of EMR system components within hospitals.

Authors' Note

All statements in this report, including its findings and conclusions, are solely those of the authors and do not necessarily represent the views of the Patient-Centered Outcomes Research Institute (the funding agency), its board of governors, or its Methodology Committee.

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Supplemental Material

The Appendix Table 1 is available with the online article at ajmq.sagepub.com.

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