Higher Electronic Health Record Functionality Is Associated with Lower Operating Costs in Urban—but Not Rural—Hospitals

Claudia A. Rhoades[1] Brian E. Whitacre[1] Alison F. Davis[2]

[1] Department of Agricultural Economics, Oklahoma State University, Stillwater, Oklahoma, United States
[2] Department of Agricultural Economics, University of Kentucky, Lexington, Kentucky, United States

Address for correspondence Claudia A. Rhoades, PhD, Department of Agricultural Economics, Oklahoma State University, 308 Agricultural Hall, Stillwater, OK 74078, United States (e-mail: alejandra.mendoza_ruiz@okstate.edu).

Appl Clin Inform 2022;13:665–676.

Abstract

Objectives The aim of the study is to examine the relationship between electronic health record (EHR) use/functionality and hospital operating costs (divided into five subcategories), and to compare the results across rural and urban facilities.

Methods We match hospital-level data on EHR use/functionality with operating costs and facility characteristics to perform linear regressions with hospital- and time-fixed effects on a panel of 1,596 U.S. hospitals observed annually from 2016 to 2019. Our dependent variables are the logs of the various hospital operating cost categories, and alternative metrics for EHR use/functionality serve as the primary independent variables of interest. Data on EHR use/functionality are retrieved from the American Hospital Association's (AHA) Annual Survey of Hospitals Information Technology (IT) Supplement, and hospital operating cost and characteristic data are retrieved from the American Hospital Directory. We include only hospitals classified as "general medical and surgical," removing specialty hospitals.

Results Our results suggest, first, that increasing levels of EHR functionality are associated with hospital operating cost reductions. Second, that these significant cost reductions are exclusively seen in urban hospitals, with the associated coefficient suggesting cost savings of 0.14% for each additional EHR function. Third, that urban EHR-related cost reductions are driven by general/ancillary and outpatient costs. Finally, that a wide variety of EHR functions are associated with cost reductions for urban facilities, while no EHR function is associated with significant cost reductions in rural locations.

Conclusion Increasing EHR functionality is associated with significant hospital operating cost reductions in urban locations. These results do not hold across geographies, and policies to promote greater EHR functionality in rural hospitals will likely not lead to short-term cost reductions.

Keywords

- electronic health records
- hospital costs
- rural hospitals
- urban hospitals

received
January 27, 2022
accepted
April 30, 2022

DOI https://doi.org/10.1055/s-0042-1750415.
ISSN 1869-0327.

Background and Significance

The U.S. health care system is one of the most advanced in the world, but it is also uncoordinated and fragmented, leading to inefficient resource allocation and rising costs.[1,2] Since 2010, 120 rural hospitals have closed and many closed facilities have exited with operating costs exceeding revenues.[3,4] The trend in rural hospital closure is a source of concern because the areas with the highest number of rural hospital closures are some of the country's most vulnerable.[5,6] Considering the rising operating costs and the toll these costs have on rural hospitals, policymakers have long been interested in finding solutions to mitigate them. Since the mid-2000s, analysts have argued that electronic health records (EHRs) are one cost-reducing strategy that could help.[7–9]

EHR is an expression that includes a range of information technologies used to collect information about patients, treatments, and outcomes.[10] Proponents believe that EHRs should increase health care quality and reduce operating expenses. Hypothesized improvements that could be translated into cost savings for hospitals include reducing errors, improving the flow of information, and performing the same task with fewer resources.[11] From a theoretical perspective, EHR systems could impact dominant input costs (labor and equipment) by improving decision making and offering decision support for treatment plans. This would raise physician efficiency and lower duplicative or problematic medication costs.[12] Alternatively, EHRs can help reduce incentives for doctors or patients who wish for more (potentially costly) care, even when the costs are significantly higher than the benefits. They could also reduce labor costs by removing unnecessary outsourced activities like advanced diagnostics, or by changes in workflow that could remove part-time labor. Early studies estimated that EHR adoption could reduce annual health spending by between $78 and $81 billion.[13,14] However, a more in-depth review of the literature on the relationship between EHRs and hospital operating costs is inconclusive. There are studies that find that EHR adoption *increases* hospital costs,[15–18] studies that find that EHR adoption *reduces* own-hospital costs,[12,19] and studies that find mixed results.[20–24]

The existing literature on the relationship between EHR and hospital costs is also largely missing a comparison of rural and urban facilities. This comparison is an important contribution of our paper, because expectations for EHR impacts across the rural/urban spectrum have not been established. Several studies have explicitly noted the differences in EHR implementation and use in rural versus urban hospitals. These studies found that smaller staff (and fewer resources generally) in rural locations led to insufficient system/process knowledge—made more difficult by tight implementation schedules[25]—and that rural hospitals were 71% less likely to consider cost reductions as a potential benefit of EHRs.[26] An additional study found that barriers to integrating EHRs with decision making tools were dramatically different in rural versus urban locations.[27] The existing literature clearly notes the cost differences that exist between rural and urban hospitals, with an early study finding that case mix and wage rates are important determinants,[28] while more recent work found that bed counts were predictive of costs per adjusted patient day.[29] This body of evidence clearly finds rural–urban hospital discrepancies in both EHR implementation and cost structure generally, but no studies we are aware of combine these two components.

We also note that a significant amount of prior research mostly focused on the *adoption* of EHRs. These adoption-focused studies observe whether an EHR system is in place at a particular time, with limited insight into its abilities or usage. Such data do not provide insight into the increased functionality of EHR over time, which could better inform the contributions of specific EHR components on operating cost efficiency. We propose that the debate about EHRs should be reframed by focusing on the effect of EHR *functionality or use* on hospital costs, as opposed to simple adoption. Several recent studies have found that there is significant variation in how hospital employees use EHRs as part of their daily workflow, with some noting the pervasiveness of "work-arounds"[30] while others found high physician satisfaction with certain functionalities (decision support, test management) but dissatisfaction with others (referral management, discharge forms).[31] One earlier study found that the ability to add new modules or functions was an important option to support workflow needs.[32] These studies help set the stage to address the question of whether increased EHR functionality is associated with better workflow / lower costs—and whether this connection holds in both rural and urban locations.

Objectives

This study examines the relationship between EHR use/functionality and hospital operating costs, over time, using varying metrics for EHR use/functionality. We perform linear regressions with hospital- and time- fixed effects on a panel of 1,596 U.S. hospitals observed annually from 2016 to 2019. Our dependent variables are the logs of hospital operating costs (broken out into five sub-categories), and alternative metrics for EHR use/functionality serve as the primary independent variables of interest. Our specification controls for the main hospital characteristics expected to impact costs, such as the total number of employees and discharges, and case mix. We run separate regressions for hospitals in rural versus urban locations to determine whether rural status impacts the EHR / cost relationship.

Methods

We match hospital level data on EHR use from the American Hospital Association's (AHA) Annual Survey of Hospitals Information Technology (IT) Supplement with cost data from the American Hospital Directory (AHD) for the years 2016 to 2019. The AHA IT supplement contains data on the hospital's EHR system along with metrics that detail the adoption, functionality, and use of EHRs within the hospital. These data have been used to document EHR access and use by federal government organizations and by academic researchers.[33–37] AHD is a private company that provides data from hospitals nationwide, using public and private sources. AHD data has also been used in recent academic research.[38,39]

We include only hospitals classified as "general medical and surgical," removing specialty hospitals. The final product of our data aggregation is a panel dataset of 1,596 hospitals with information on both hospital operating costs, and EHR adoption/functionality/use for all 4 years of the analysis. Rural hospitals were identified based on the Federal Office of Rural Health Policy's list of rural zip codes.[40] Forty-one percent of the hospitals in our dataset reside in a rural location. The main variables of interest are hospital operating costs (broken out into five subcategories discussed below), and EHR adoption/functionality/use.

The AHD database breaks total hospital operating costs into five subcategories: general/ancillary, inpatient, outpatient, other reimbursable, and other general services costs. This data comes from the Medicare Cost Reports, namely worksheets A, B, and C.[41,42] Notably, EHR-related costs are included as "Capital Related Costs" on worksheet B (part of general/ancillary) so that EHR improvements are captured in the cost data. AHD contains annual data for over 7,000 U.S. hospitals, but we link only to those 1,596 hospitals completing all 4 years of the AHA IT survey. The AHD data contain hospital characteristics likely to influence hospital operating costs that can serve as control variables.[43] This includes the number of beds, employees, discharges, acute days, and case mix index (CMI), which has been shown to be an important contributor to hospital operating costs.[44–46]

Our primary independent variables of interest relate to EHR adoption, functionality, and use. The AHA IT database includes several measures that can serve this purpose, with the three we focus on defined below.

1. Adoption: a dummy variable for the presence of a certified EHR.
2. Functionality: assigned values 0 to 27 for the number of computerized system functions that are "fully implemented across all units." The computerized system functionalities are divided into five subcategories: electronic clinical documentation, results viewing, computerized provider order entry (CPOE), decision support, and other functionalities.
3. Use: assigned values 0 to 10 for the number of processes or products generated using the EHR system (for example, creating an individual provider performance profile).

The AHA IT survey questions used to derive these measures are provided in ►Supplementary Appendix A (available in the online version), and the computerized system functionalities comprising the five subcategories are listed in ►Supplementary Appendix B (available in the online version).

To examine the relationship between EHR and hospital operating costs, we need to isolate the effect of the EHR metrics on hospital operating costs from alternative effects related to hospital characteristics and time trends. We follow Atasoy et al[18] in estimating a panel regression with hospital- and year-fixed effects on our panel of hospitals observed annually from 2016 to 2019:

$$logcost_{it} = \boldsymbol{\alpha X_{it}} + \theta EHR_{it} + \tau_t + \mu_i + \varepsilon_{it}$$

where $logcost_{it}$ is the log of hospital operating costs for hospital i in year t, $\boldsymbol{X_{it}}$ are controls for hospital characteristics that change over time (log of number of beds, log of total employees, log of total discharges, log of total acute days, and CMI); τ_t captures the average changes to hospital operating costs over time; μ_i is a hospital fixed effect; EHR_{it} can be modified to include any of the three EHR metrics described above; and ε_{it} is the independent random error term.

Our main parameter of interest is $\boldsymbol{\theta}$, with the hypothesis that it will be negative and statistically significant only for EHR functionality (metric 2) and/or use (metric 3). The fixed effects model allows us to account for individual heterogeneity (i.e., hospital-specific effects such as employee attitude toward EHRs) and year effects (capturing any national health care shock or trend) to assess the net impact of the predictors on the outcome variable.

Initially, we employ three fixed-effects panel regressions with the log of total hospital operating costs as the dependent variable and our three metrics for EHR adoption, functionality, and use as the main independent variables of interest. We explore these specifications across subsets of rural and urban hospitals. Subsequently, we perform three additional fixed effects panel regressions using the log of each dominant cost sub-category as dependent variables to inform us about the specific types of costs that seem to be most responsive to EHR functionality. Finally, we explore which of the EHR functionalities (subcategories of metric 2; detailed in ►Supplementary Appendix B, available in the online version) are most related to the cost subcategories of interest, and whether these relationships hold across rural and urban geographies.

Our sample is limited by hospitals completing all 4 years of the IT supplement survey. Since self-selection may occur, to generalize our results we follow Parasrampuria and Henry[34] and use a logistic regression model to predict the propensity of AHA IT survey response for all 4 years as a function of hospital characteristics, including size, ownership, type of facility, CMI, and urban status. Hospital-level weights were derived by the inverse of the predicted propensity and used in our analysis. Detailed information regarding the logistic regression model is provided in ►Supplementary Appendix C and ►Supplementary Appendix D (available in the online version).

Given the panel nature of the data and the differences in hospital sizes, costs, and EHR use/functionality between rural and urban hospitals that we observe, the presence of heteroskedasticity is likely. To test for groupwise heteroskedasticity in the fixed-effects regression models we perform a Modified Wald test. To test for nonlinearity we use the command NLCHECK in STATA.[47]

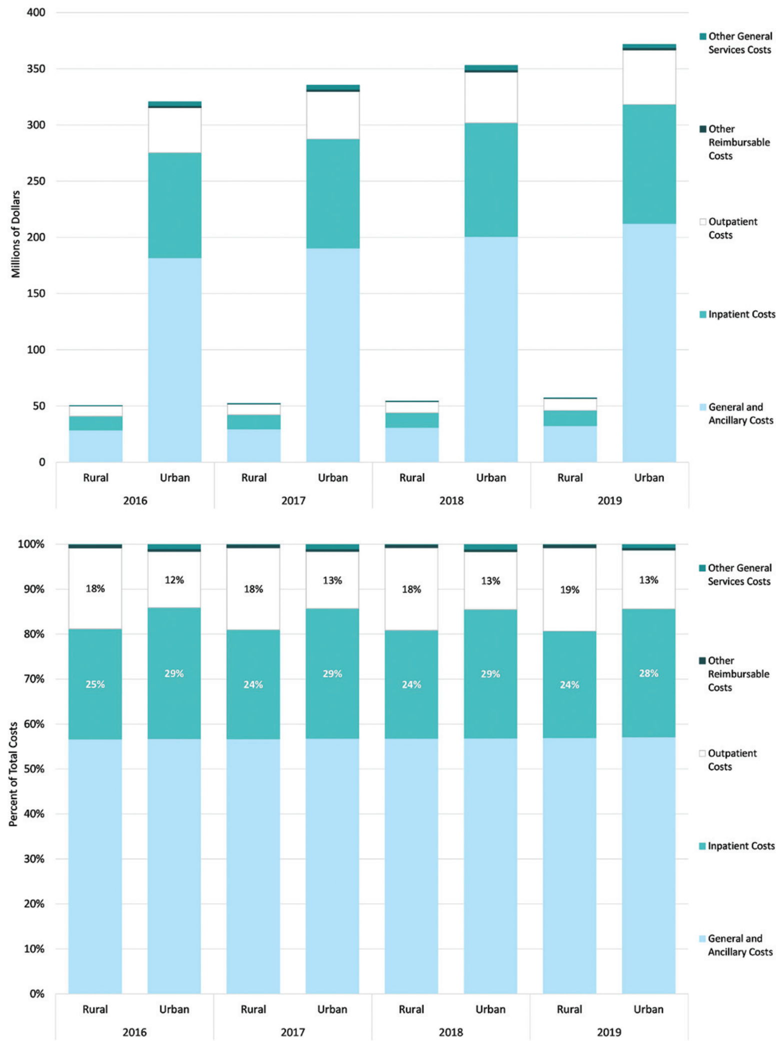

Fig. 1 Cost breakouts and cost composition for urban and rural hospitals (in millions of dollars), 2016–2019.

Results

►**Fig. 1** demonstrates the significant variation in costs for rural versus urban hospitals in our sample, with total costs seven times higher in urban locations. It also highlights an increase in costs over time (particularly for urban hospitals), suggesting that controlling for time-dependent cost increases is an important part of our econometric approach.

►**Fig. 1** further demonstrates that the cost composition is different across geographies (bottom panel). While general ancillary services costs represent the majority of costs (57%) in all hospitals, outpatient costs are a larger percentage of costs in rural (18–19%) versus urban (12–13%) locations. This is consistent with recent research documenting an increase in outpatient visits among rural hospitals—while also noting the importance of this revenue stream for rural facilities.[48] If EHR functionality is revealed to impact overall costs (as hypothesized), cost sub-components driving that relationship is an interesting follow-up question.

Summary statistics for the independent variables are presented in ►**Table 1**, which indicates that EHR adoption is high regardless of rural/urban status. This is consistent with recent studies.[49] The second and third metrics (functionality and use) exhibit more variation, both over time and across rural/urban facilities. Rural hospitals added an average of three EHR functions between 2016 and 2019, while urban facilities reached almost full functionality by 2019. Notably, the "functionality gap" between rural and urban hospitals is reduced over time, moving from 1.8 additional functions for urban locations in 2016 to only 1.1 by 2019. The third measure, EHR use, is higher for urban hospitals but increases only marginally over time, with all hospitals adding only 0.2 uses on average between 2016 and 2018 (the 2019 survey did not include the "use" questions).

The values of the control characteristics vary significantly by rural/urban status (►**Supplementary Appendix E**, available in the online version). In 2019, urban hospitals had over four times as many beds, five times as many employees, and ten times as many total acute days when compared with their rural counterparts. The CMI is also much higher in urban facilities. These rural–urban differences hold in all years of the analysis.

►**Table 2** summarizes the results of our initial regressions. For the full dataset (rural and urban hospitals combined), none of the EHR metrics are significantly associated with the log of total operating costs at the $p < 0.05$ level. It is

Table 1 EHR metrics and *t*-tests by rural/urban status

	Variable	2016			2017			2018			2019		
		Rural	Urban	Diff.	Rural	Urban	Diff.	Rural	Urban	Diff.	Rural	Urban	Diff.
1	Simple adoption (certified EHR)	0.98	0.98		0.97	0.98	**	0.96	0.98	*	0.97	0.98	
2	All EHR functionalities	21.77	23.57	***	22.23	24.08	***	24.46	25.65	***	24.89	25.97	***
	Electronic clinical documentation	5.33	5.59	***	5.40	5.74	***	5.78	5.90	***	5.84	5.92	***
	Results viewing	5.29	5.82	***	5.34	5.88	***	5.66	5.94	***	5.75	5.96	***
	Computerized provider order entry	4.36	5.55	***	4.48	4.84	***	4.80	4.94	***	4.85	4.96	***
	Decision support	4.98	5.55	***	5.13	5.61	***	5.52	5.83	***	5.62	5.87	***
	Other functionalities	1.80	1.87		1.89	2.01	**	2.69	3.05	***	2.84	3.24	***
3	EHR use	6.38	8.28	***	6.40	8.36	***	6.54	8.54	***			
	Number of observations	655	941		655	941		655	941		655	941	

Abbreviation: EHR, electronic health record.
[a]*, **, and *** represent statistically significant differences between rural and urban facilities at the $p < 0.10$, $p < 0.05$, and $p < 0.01$, levels, respectively.
[b]American Hospital Association's (AHA) Annual Survey of Hospitals Information Technology Supplement, 2016–2019. The 2019 AHA IT survey did not include the "EHR Use" question.

important to note that, although not statistically significant, the coefficient of EHR functionality (metric 2) is negative, following the hypothesized direction. Notably, the coefficients for simple adoption and use (metrics 1 and 3) are positive—although again are not statistically significant. The control variables have the expected positive signs, suggesting that the model behaves according to economic theory. In particular, higher case mix indices, more beds, discharges, and total acute days are associated with larger hospital operating costs. These variables measure the size and scope of a hospital; it is a reasonable finding that larger hospitals have higher costs. The overall fits of the panel regressions are quite good with R^2 values exceeding 0.93.

When the specifications are explored across subsets of rural and urban hospitals, we find that only urban hospitals appear to benefit from operating cost decreases associated with increasing EHR functionality (►Table 2). The respective coefficient suggests that an additional EHR function is associated with total costs reductions of 0.14%. Notably, higher levels of EHR *use* are associated with higher costs in urban hospitals, suggesting that new EHR activities lead to additional costs. The control variables demonstrate that the number of employees and total discharges are predictive of costs in urban hospitals, but not rural ones. The overall fit of the models remains strong.

We now turn to the effects of EHR functionality on subcategories of costs (►Table 3). We focus only on the three dominant cost sub-categories (general/ancillary, outpatient, and inpatient), which account for approximately ninety-eight percent of all hospital operating costs (►Fig. 1). Even though we did not find a significant relationship between EHR functionality and total hospital operating costs for the full dataset (at the $p < 0.05$ level), ►Table 3 demonstrates that once we examine the relationship between EHR functionality and each cost sub-category separately, we find a significant and negative relationship between EHR functionality and outpatient costs ($\boldsymbol{\theta} = -0.0016$, $p = 0.019$), for the full dataset. For general/ancillary costs and inpatient costs the estimated coefficients for the control variables are as hypothesized, however, the results do not show a significant relationship with aggregate EHR functionality.

►Table 3 extends the sub-category cost analysis to explore rural versus urban hospitals separately, and indicates that general/ancillary costs and outpatient costs have negative relationships with EHR functionality in urban hospitals. Outpatient costs demonstrate the largest relationship ($\boldsymbol{\theta} = -0.0022$, $p = 0.036$). The associated coefficient implies that for urban hospitals a one-unit increase in EHR functionality is associated with a 0.22% decrease in outpatient costs. General/ancillary costs, which were not statistically significant for the full dataset, show a significant negative association with EHR functionality for urban hospitals ($\boldsymbol{\theta} = -0.0014$, $p = 0.034$). For rural hospitals, no cost category shows a significant relationship with EHR functionality. This result holds when the rural sample is limited to critical access hospitals (not shown).

Lastly, we explore the five sub-categories of EHR functionality to narrow down which EHR functionalities are most

Table 2 Effects of EHR metrics on total hospital operating costs

	Full dataset						Rural						Urban					
DV	log total costs		log total costs		log total costs		log total costs		log total costs		log total costs		log total costs		log total costs		log total costs	
	(1)		(2)		(3)		(1)		(2)		(3)		(1)		(2)		(3)	
EHR metric	Adoption		Functionality		Use		Adoption		Functionality		Use		Adoption		Functionality		Use	
EHR	0.0057		−0.0009	*	0.0006		0.0057		−0.0005		−0.0002		0.0113		−0.0014	**	0.0019	***
	(0.0096)		(0.0005)		(0.0007)		(0.0106)		(0.0006)		(0.0011)		(0.0145)		(0.0006)		(0.0006)	
Case Mix Index	0.0906	***	0.0900	***	0.1239	***	0.1257	***	0.1254	***	0.1364	*	0.0641	*	0.0637	*	0.1192	***
	(0.0317)		(0.0313)		(0.0432)		(0.0443)		(0.0439)		(0.0739)		(0.0375)		(0.0376)		(0.0271)	
Log tot. beds	0.0827	***	0.0822	***	0.0816	***	0.0872	***	0.0868	***	0.0872	**	0.0528	***	0.0529	***	0.0549	***
	(0.0192)		(0.0192)		(0.0242)		(0.0298)		(0.0297)		(0.0379)		(0.0180)		(0.0179)		(0.0193)	
Log tot. employees	0.0224		0.0257		0.0111		0.0085		0.0088		−0.0100		0.1312	***	0.1301	***	0.0830	***
	(0.0225)		(0.0224)		(0.0371)		(0.0197)		(0.0196)		(0.0363)		(0.0228)		(0.0228)		(0.0185)	
Log tot. discharges	0.0713	**	0.0706	**	0.0434		0.0298		0.0289		0.0252		0.1302	***	0.1306	***	0.0640	***
	(0.0330)		(0.0330)		(0.0302)		(0.0407)		(0.0404)		(0.0477)		(0.0392)		(0.0402)		(0.0217)	
Log tot. acute days	0.0766	***	0.0769	***	0.1106	***	0.0819	**	0.0830	**	0.1056	***	0.0922	**	0.0897	**	0.1426	***
	(0.0285)		(0.0285)		(0.0262)		(0.0330)		(0.0327)		(0.0357)		(0.0446)		(0.0454)		(0.0307)	
Hospital fixed effects	Yes		Yes		Yes		Yes		Yes		Yes		Yes		Yes		Yes	
Year fixed effects	Yes		Yes		Yes		Yes		Yes		Yes		Yes		Yes		Yes	
Overall R^2	0.9362		0.9358		0.9351		0.8423		0.8415		0.8329		0.9202		0.9198		0.9161	
Number Observations	6,336		6,336		4,749		2,604		2,604		1,952		3,732		3,732		2,797	

Abbreviation: EHR, Electronic Health Record. EHR Metric refers to (1) EHR Adoption, (2) EHR Functionality, and (3) EHR Use in subsequent columns.
[a]Unit of observation is hospital-year.
[b]Sample includes annual data from 2016 to 2019.
[c]Robust standard errors, clustered by hospital, in parenthesis.
[d]*$p< 0.10$, **$p< 0.05$, ***$p< 0.01$.
[e]The American Hospital Association's (AHA) Information Technology Supplement did not include the variable used in this study to measure EHR use (number of products) in 2019; thus the number of observations in model (3) are lower.

Table 3 Effects of EHR Functionality on cost sub-categories

	Full dataset			Rural			Urban		
DV	Log general and ancillary costs	Log inpatient costs	Log outpatient costs	Log general and ancillary costs	Log inpatient costs	Log outpatient costs	Log general and ancillary costs	Log inpatient costs	Log outpatient costs
EHR functionality	−0.0005	−0.0009	−0.0016 **	0.0001	−0.0007	−0.0012	−0.0014 **	−0.0005	−0.0022 **
	(0.0006)	(0.0007)	(0.0007)	(0.0008)	(0.0008)	(0.0008)	(0.0006)	(0.0008)	(0.0011)
Case mix index	0.1176 ***	0.0180	0.1018 **	0.1420 ***	0.0143	0.1239 **	0.1039 **	0.0527	0.0827
	(0.0372)	(0.0515)	(0.0443)	(0.0503)	(0.0693)	(0.0623)	(0.0510)	(0.0535)	(0.0531)
Log tot. beds	0.0531 **	0.1380 ***	0.0814 ***	0.0557	0.1383 ***	0.0843 *	0.0299	0.1045 ***	0.0661 **
	(0.0248)	(0.0299)	(0.0316)	(0.0372)	(0.0447)	(0.0478)	(0.0218)	(0.0211)	(0.0265)
Log tot. employees	0.0377 *	0.0057	0.0382	0.0232	−0.0134	0.0153	0.1244 ***	0.1106 ***	0.2015 ***
	(0.0195)	(0.0264)	(0.0278)	(0.0192)	(0.0216)	(0.0218)	(0.0249)	(0.0237)	(0.0360)
Log tot. discharges	0.0741 *	0.0816 **	0.0719	0.0246	0.0522	−0.0112	0.1432 ***	0.1406 ***	0.1698 ***
	(0.0385)	(0.0404)	(0.0500)	(0.0443)	(0.0517)	(0.0598)	(0.0536)	(0.0505)	(0.0604)
Log tot. acute days	0.0802 **	0.1674 ***	−0.0207	0.0981 ***	0.1463 ***	0.0415	0.0743	0.2377 ***	−0.1213 *
	(0.0330)	(0.0419)	(0.0423)	(0.0355)	(0.0543)	(0.0460)	(0.0553)	(0.0612)	(0.0624)
Hospital fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Overall R^2	0.9348	0.9287	0.7587	0.8463	0.8230	0.4982	0.9073	0.9133	0.7362
Number of observations	6,336	6,336	6,336	2,604	2,604	2,604	3,732	3,732	3,732

Abbreviation: EHR, electronic health record.
[a] Unit of observation is hospital-year.
[b] Sample includes annual data from 2016 to 2019.
[c] Robust standard errors, clustered by hospital, in parenthesis.
[d] *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

directly responsible for the decreasing relationships with the main sub-categories of costs. We apply eq. (1) using general/ancillary, inpatient, and outpatient costs as our dependent variables, and each of the five sub-categories of EHR functionalities as our primary independent variables of interest. We include each sub-category of EHR functionality in separate regressions due to multicollinearity concerns.

The results (►Table 4) suggest that for the full dataset, increasing electronic clinical documentation is associated with a significant reduction in general/ancillary costs. The associated coefficient implies cost reductions of 0.44% for each additional electronic clinical documentation function. For inpatient costs, there are no significant reductions associated with any EHR functionality at the $p < 0.05$ level. Outpatient costs demonstrate negative and significant relationships with electronic clinical documentation, and decision support. When all cost categories are aggregated together, only electronic clinical documentation demonstrates a significantly negative relationship ($\boldsymbol{\theta} = -0.0048$, $p < 0.01$; not shown in ►Table 4).

When we extend the analysis to look at rural versus urban hospitals separately, we find that no EHR functionality is significantly associated with costs reductions in rural hospitals (►Table 4). Notably, no EHR functionalities are associated with significant cost reductions for *outpatient* costs in rural areas, which make up a larger proportion of total costs when compared with urban facilities (►Fig. 1). Alternatively, a variety of EHR functionalities are associated with outpatient and general/ancillary costs reductions in urban locations. For urban hospitals, CPOE ($p = 0.042$) is associated with significant outpatient cost reductions (0.74% for each additional function). In the general/ancillary category, electronic clinical documentation ($\boldsymbol{\theta} = -0.0059$, $p = 0.012$) and results viewing ($\boldsymbol{\theta} = -0.0066$, $p = 0.036$) are associated with significant cost reductions in urban facilities. The trends are similar for aggregate urban operating costs (not shown in ►Table 4), where electronic clinical documentation ($\boldsymbol{\theta} = -0.0047$), results viewing ($\boldsymbol{\theta} = -0.0066$), and CPOE ($\boldsymbol{\theta} = -0.0041$) all demonstrate significantly negative relationships at the $p < 0.05$ level.

Discussion

EHRs have become commonplace in U.S. hospitals, but prior research has been unclear about their relationship with operating costs. Rural and urban hospital employees interact with EHRs differently, with fewer resources and expertise available in rural locations. Testing whether the underlying relationships differ across geography can have important implications for future EHR policy. Our results suggest that EHR *functionality*, and not simple adoption, is associated with hospital operating cost reductions in urban areas. This finding is of particular interest because previous studies have largely focused on simple EHR adoption as the metric of interest. The associated coefficient suggests total operating costs savings of 0.14% for an average urban hospital for each additional EHR function (►Table 2). This finding is striking because it suggests a short-term impact: increased EHR functionality in year *t* is associated with reduced hospital operating costs in that same year. Our finding that EHR *use* is associated with significant cost increases in urban hospitals may be due to the nature of the survey questions asked. We hypothesize that alternative metrics for EHR use, such as those that are part of the Centers for Medicare and Medicaid Services' (CMS) Promoting Interoperability Program,[50] could show different relationships with cost.

While the finding that increasing EHR functionality is associated with lower hospital operating costs is likely of interest to hospital administrators, the results are less optimistic for rural hospitals. EHR functionality is not associated with significant cost decreases at the aggregate level—or for any cost sub-category—among rural hospitals. Therefore, investing in additional total EHR functionality does not appear to be a mechanism to reduce costs for rural hospitals.

In addition, our results show that urban EHR-related cost reductions are driven by both general/ancillary and outpatient costs, but no such relationship is observed for rural hospitals (►Table 3). This is important because of the higher proportion of costs associated with outpatient services in rural facilities (►Fig. 1). This may be because physician practices that send patients to hospitals for outpatient procedures are more likely to participate in health information exchanges in urban locations, resulting in less time (and cost) spent gathering data at the hospital. An alternative hypothesis is that the lack of a relationship is driven by the fact that rural residents are less likely to manage their personal health information online.[51] Additional research should explore why increased EHR functionality is associated with reduced outpatient costs in urban, but not rural, facilities.

Finally, breaking out EHR functions into sub-categories offers insight into how different EHR capabilities might impact costs across geographies. The results suggest that no EHR functionality sub-category has a significant effect on rural hospitals' operating costs (►Table 4). In urban hospitals, the largest impacts to hospital operating costs are seen for CPOE (outpatient costs: $\boldsymbol{\theta} = -0.0074$). However, urban hospitals have already invested in nearly all CPOE capabilities (4.96 out of 5 in 2019) and so attempting to reduce costs simply by adding more CPOE functionality is not an option for most facilities. Notably, functionality associated with telehealth (included under other functionality) was not associated with cost reductions for any hospitals; however, the period of analysis was prior to the COVID-19 pandemic when telehealth use soared.

These findings have implications for policy and research discussions. The negative relationship between increased EHR functionality and total hospital operating costs in urban hospitals suggests that the proper way to think of EHR implementation is not in terms of simple adoption, but as a longer-term investment whose payoff is realized as functionality is added. Rural facilities lag behind their urban counterparts in terms of EHR functionality, but policy efforts to improve this functionality should acknowledge the limited potential for short-term cost reductions. The discrepancies across rural/urban locations imply that additional

Table 4 Effects of sub-categories of EHR functionality on general/ancillary, inpatient, and outpatient costs

	Full dataset			Rural			Urban		
Dv	Log ancillary costs	Log inpatient costs	Log outpatient costs	Log ancillary costs	Log inpatient costs	Log outpatient costs	Log ancillary costs	Log inpatient costs	Log outpatient costs
Electronic clinical documentation	−0.0044 **	−0.0043 *	−0.0057 **	−0.0028	−0.0047	−0.0043	−0.0059 **	0.0003	−0.0069 *
	(0.0019)	(0.0025)	(0.0025)	(0.0024)	(0.0032)	(0.0031)	(0.0023)	(0.0030)	(0.0041)
Results viewing	−0.0003	−0.0022	−0.0027	0.0008	−0.0025	−0.0021	−0.0066 **	−0.0012	−0.0080 *
	(0.0027)	(0.0025)	(0.0025)	(0.0031)	(0.0029)	(0.0028)	(0.0032)	(0.0037)	(0.0042)
Computerized provider order entry	−0.0012	−0.0035 *	−0.0042 *	0.0001	−0.0025	−0.0021	−0.0029	−0.0044	−0.0074 **
	(0.0021)	(0.0021)	(0.0025)	(0.0027)	(0.0027)	(0.0031)	(0.0021)	(0.0027)	(0.0036)
Decision support	−0.0001	−0.0008	−0.0050 **	0.0011	−0.0004	−0.0044	−0.0021	−0.0004	−0.0057 *
	(0.0017)	(0.0019)	(0.0022)	(0.0023)	(0.0024)	(0.0029)	(0.0022)	(0.0027)	(0.0029)
Other functionalities	−0.0004	−0.0007	−0.0023	0.0006	0.0003	−0.0024	−0.0012	−0.0011	−0.0009
	(0.0018)	(0.0019)	(0.0024)	(0.0026)	(0.0029)	(0.0034)	(0.0019)	(0.0020)	(0.0032)
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hospital Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Overall R^2	0.9349	0.9289	0.8081	0.8465	0.8236	0.5015	0.9077	0.9133	0.7374
Number Observations	6,336	6,336	6,336	2,604	2,604	2,604	3,732	3,732	3,732

Abbreviation: EHR, Electronic Health Record.
[a]EHR functionalities introduced individually (i.e., five separate regressions for each DV).
[b]Unit of observation is hospital-year.
[c]Sample includes annual data from 2016 to 2019.
[d]Robust standard errors, clustered by hospital, in parenthesis.
[e]$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

research should attempt to tackle *why* specific EHR relationships are so much stronger for urban facilities. Specifically, insight into why EHR functionalities reduce *outpatient* costs in urban, but not rural, hospitals would be particularly useful given the increasing importance of outpatient services for rural facilities.

As an empirical study, our analysis has several limitations. First, we focus on distinct EHR metrics over a particular period; however, there may be better ways to measure EHR use/functionality over time. It is worth noting that we did explore several additional EHR metrics included in the AHA IT Supplement (for example, integration of summary care records received electronically; electronic availability of clinical information) and found no impact on any type of costs for rural or urban hospitals. Second, we are limited by the self-reported nature of the IT supplement survey data, which may introduce measurement error. Our approach does not explicitly control for the EHR vendor (because it does not vary over time for the vast majority of our hospitals). The AHA IT survey does capture this data for each hospital, and here we see that while the top three vendors (Cerner, Epic, and Meditech) made up 85% of the urban systems in our sample, they were only chosen by 63% of rural facilities. Four smaller, alternative vendors (CPSI, Healthland, Evident, and Medhost) captured 22% of the rural market but only 1% of urban hospitals. The support network offered by the vendor could be important for how the system is rolled out by the hospital and the resulting relationship with workflow/costs.

We also use a dichotomous measure of rurality, and an avenue for future research is to explore whether these results hold across alternative definitions (such as micropolitan vs. non-core counties, or the nine-category rural–urban continuum codes defined by the U.S. Economic Research Service).[52] Lastly, our two-way fixed effects model controls for time invariant unobserved hospital characteristics; however, there may be time-varying hospital characteristics that are not being captured by our model, such as changes to staff education levels or hospital administration. These unobserved time-varying characteristics could be a potential source of bias. Other potential confounders include baseline outcomes and for-profit status. While our empirical methodology is an improvement on prior cross-sectional studies, an alternative approach is needed to make a strict causal argument.

Conclusion

Policy discourse on EHRs has moved beyond simple possession of an EHR, with CMS' 2021 Promoting Interoperability Program requiring information on functionalities like e-prescribing and provider-to-patient exchange.[50] Our results demonstrate that specific types of EHR functionality are associated with reduced hospital operating costs in the short term. They also highlight that rurality is an important consideration, as cost reductions are only realized in urban hospitals. A better understanding of why these rural/urban differences exist is crucial, if only because rural hospitals are more likely to operate on thin margins where any cost reduction could prove vital to remaining open. Importantly, urban hospitals are nearing maximum functionality across several sub-categories shown to impact costs, so policies emphasizing the implementation of those specific EHR functions for urban locations may have limited impact. Exploring the impacts of enhanced EHR functionality where adoption is lower (telehealth; remote patient monitoring) is an opportunity for future research, particularly in light of increased demand for these activities due to COVID-19.

Clinical Relevance Statement

Since their development, EHR proponents have argued that they can help hospitals reduce operating costs. However, the literature on the subject up to date is mixed. The results of this study indicate that specific types of EHR functionality are associated with reduced hospital operating costs in the short term. However, such cost reductions are only observed in urban hospitals.

Multiple Choice Questions

1. For the full dataset (urban and rural hospitals combined), which cost subcategory is significantly, negatively associated with increased EHR functionality?
   a. General and ancillary costs.
   b. Outpatient costs.
   c. Inpatient costs.
   d. None of the above.

   Correct Answer: The correct answer is option b. When we explore the effects of EHR functionality on subcategories of costs for the full dataset, we find that the negative relationship between EHR functionality and total hospital operating costs is driven by outpatient costs.

2. Once we focus exclusively on rural hospitals, which cost subcategory is significantly, negatively associated with increased EHR functionality?
   a. General and ancillary costs.
   b. Outpatient costs.
   c. Inpatient costs.
   d. None of the above.

   Correct Answer: The correct answer is option d. When we extend the analysis to look at rural hospitals separately, we find that no cost subcategory shows a significant relationship with EHR functionality.

Protection of Human and Animal Subjects

This research included only secondary analysis of existing hospital-level data that did not include any living individuals or any identifiable private information. As such, no Institutional Review Board (IRB) oversight was required.

Data Accessibility

The data that support the findings of this study are available from the American Hospital Association's (AHA) Information Technology (IT) supplement and the

American Hospital Directory (AHD), but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available.

Author Contributions

C.A.R. aggregated the relevant data, performed the regression analysis, and led the writing of the manuscript. B.E.W. helped with data gathering, led the development of the econometric approach, reviewed the regression results, and contributed to the manuscript writing. A.F.D. contributed to the manuscript writing and provided funding for C.A.R.'s assistantship and the relevant data purchases. All listed authors in this manuscript have approved this final version.

Funding

This study was supported by the Federal Office of Rural Health Policy (FORHP), Health Resources and Services Administration (HRSA), U.S. Department of Health and Human Services (HHS) under cooperative agreement # U1ZRH33331–02–01. The information, conclusions, and opinions expressed in this article are those of the authors and no endorsement by FORHP, HRSA, HHS, Oklahoma State University or University of Kentucky is intended or should be inferred.

Conflict of Interest

None declared.

References

1 PricewaterhouseCoopers. L. L. P. The price of excess: Identifying waste in healthcare spending. Health Research Institute; 2008

2 Berwick DM, Hackbarth AD. Eliminating waste in US health care. JAMA 2012;307(14):1513–1516

3 Topchik M, Gross K, Pinette M, et al. The rural health safety net under pressure: rural hospital vulnerability. Chartis Center for Rural Health2020 Accessed February 10, 2021 at: https://www.chartis.com/forum/insight/the-rural-health-safety-net-under-pressure-rural-hospital-vulnerability/

4 Kaufman BG, Thomas SR, Randolph RK, et al. The rising rate of rural hospital closures. J Rural Health 2016;32(01):35–43

5 Thomas SR, Holmes GM, Pink GH. To what extent do community characteristics explain differences in closure among financially distressed rural hospitals? J Health Care Poor Underserved 2016; 27(4A):194–203

6 Hsia RY, Kellermann AL, Shen YC. Factors associated with closures of emergency departments in the United States. JAMA 2011;305 (19):1978–1985

7 Wang SJ, Middleton B, Prosser LA, et al. A cost-benefit analysis of electronic medical records in primary care. Am J Med 2003;114 (05):397–403

8 Ford EW, Menachemi N, Phillips MT. Predicting the adoption of electronic health records by physicians: when will health care be paperless? J Am Med Inform Assoc 2006;13(01):106–112

9 Payne TH, Bates DW, Berner ES, et al. Healthcare information technology and economics. J Am Med Inform Assoc 2013;20(02): 212–217

10 Häyrinen K, Saranto K, Nykänen P. Definition, structure, content, use and impacts of electronic health records: a review of the research literature. Int J Med Inform 2008;77(05):291–304

11 Girosi F, Meili R, Scoville R. Extrapolating evidence of health information technology savings and costs. RAND Corporation2005 Accessed March 21, 2021 at: https://www.rand.org/pubs/monographs/MG410.html

12 Borzekowski R. Measuring the cost impact of hospital information systems: 1987-1994. J Health Econ 2009;28(05):938–949

13 Hillestad R, Bigelow J, Bower A, et al. Can electronic medical record systems transform health care? Potential health benefits, savings, and costs. Health Aff (Millwood) 2005;24(05): 1103–1117

14 Walker J, Pan E, Johnston D, et al. The value of health care information exchange and interoperability: there is a business case to be made for spending money on a fully standardized nationwide system. Health Aff (Millwood) 2005;24(01):5–10

15 Sidorov J. It ain't necessarily so: the electronic health record and the unlikely prospect of reducing health care costs. Health Aff (Millwood) 2006;25(04):1079–1085

16 Furukawa MF, Raghu TS, Shao BB. Electronic medical records, nurse staffing, and nurse-sensitive patient outcomes: evidence from California hospitals, 1998-2007. Health Serv Res 2010;45 (04):941–962

17 Teufel RJ II, Kazley AS, Ebeling MD, Basco WT Jr. Hospital electronic medical record use and cost of inpatient pediatric care. Acad Pediatr 2012;12(05):429–435

18 Atasoy H, Chen PY, Ganju K. The spillover effects of health IT investments on regional healthcare costs. Manage Sci 2018;64 (06):2515–2534

19 Amarasingham R, Plantinga L, Diener-West M, Gaskin DJ, Powe NR. Clinical information technologies and inpatient outcomes: a multiple hospital study. Arch Intern Med 2009;169(02):108–114

20 Himmelstein DU, Wright A, Woolhandler S. Hospital computing and the costs and quality of care: a national study. Am J Med 2010; 123(01):40–46

21 Agha L. The effects of health information technology on the costs and quality of medical care. J Health Econ 2014;34:19–30

22 Dranove D, Forman C, Goldfarb A, et al. The trillion dollar conundrum: complementarities and health information technology. Am Econ J Econ Policy 2014;6:239–270

23 Jones SS, Rudin RS, Perry T, Shekelle PG. Health information technology: an updated systematic review with a focus on meaningful use. Ann Intern Med 2014;160(01):48–54

24 Highfill T. Do hospitals with electronic health records have lower costs? A systematic review and meta-analysis. Int J Healthc Manag 2019;13(01):65–71

25 Craven CK, Sievert MC, Hicks LL, Alexander GL, Hearne LB, Holmes JH. CAH to CAH: EHR implementation advice to critical access hospitals from peer experts and other key informants. Appl Clin Inform 2014;5(01):92–117

26 Houser SH, Au D, Weech-Maldonado R. The impact of geography on hospital electronic health records implementation in Alabama: implications for meaningful use. Appl Clin Inform 2011; 2(03):270–283

27 Puccinelli-Ortega N, Cromo M, Foley KL, et al. Facilitators and barriers to implementing a digital informed decision making tool in primary care: a qualitative study. Appl Clin Inform 2022;13 (01):1–9

28 Cromwell J, Mitchell JB, Calore KA, Iezzoni L. Sources of hospital cost variation by urban-rural location. Med Care 1987;25(09): 801–829

29 Coyne JS, Richards MT, Short R, Shultz K, Singh SG. Hospital cost and efficiency: do hospital size and ownership type really matter? J Healthc Manag 2009;54(03):163–174

30 Assis-Hassid S, Grosz BJ, Zimlichman E, Rozenblum R, Bates DW. Assessing EHR use during hospital morning rounds: a multifaceted study. PLoS One 2019;14(02):e0212816

31 Schopf TR, Nedrebø B, Hufthammer KO, Daphu IK, Lærum H. How well is the electronic health record supporting the clinical tasks of hospital physicians? A survey of physicians at three Norwegian hospitals. BMC Health Serv Res 2019;19 (01):934

32 Silow-Carroll S, Edwards JN, Rodin D. Using electronic health records to improve quality and efficiency: the experiences of leading hospitals. Issue Brief (Commonw Fund) 2012;17(01): 1–40
33 Charles D, Gabriel M, Furukawa MF. Adoption of electronic health record systems among US non-federal acute care hospitals: 2008–2012. ONC Data Brief 2013;9:1–9
34 Parasrampuria S, Henry J. Hospitals' use of electronic health records data, 2015–2017. ONC Data Brief; 2019
35 Adler-Milstein J, DesRoches CM, Furukawa MF, et al. More than half of US hospitals have at least a basic EHR, but stage 2 criteria remain challenging for most. Health Aff (Millwood) 2014;33(09): 1664–1671
36 Walker DM, Diana ML. Hospital adoption of health information technology to support public health infrastructure. J Public Health Manag Pract 2016;22(02):175–181
37 Adler-Milstein J, Holmgren AJ, Kralovec P, Worzala C, Searcy T, Patel V. Electronic health record adoption in US hospitals: the emergence of a digital "advanced use" divide. J Am Med Inform Assoc 2017;24(06):1142–1148
38 Brewster AL, Lee S, Curry LA, Bradley EH. Association between community social capital and hospital readmission rates. Popul Health Manag 2019;22(01):40–47
39 Sharma R, Zachrison KS, Viswanathan A, et al. Trends in telestroke care delivery: a 15-year experience of an academic hub and its network of spokes. Circ Cardiovasc Qual Outcomes 2020;13(03): e005903
40 Health Resources and Services Administration. FORHP Eligible ZIP Codes. Federal Office of Rural Health Policy Data Files. 2020 Accessed January 15, 2021 at: https://www.hrsa.gov/rural--health/about-us/definition/datafiles.html
41 American Hospital Directory. Department Definitions and Methodology: Cost Center Statistics. 2021 Accessed July 14, 2021 at: https://www.ahd.com/definitions/dept_rcc.html
42 American Hospital Directory. Department Definitions and Methodology: General Service Costs. 2021 Accessed July 14, 2021 at: https://www.ahd.com/definitions/dept_gen.html
43 American Hospital Directory. Definitions and Methodology: Hospital Statistics. 2021 Accessed July 14, 2021 at: https://www.ahd.com/definitions/statistics.html
44 Watts CA, Klastorin TD. The impact of case mix on hospital cost: a comparative analysis. Inquiry 1980;17(04):357–367
45 Hay JW. Hospital cost drivers: an evaluation of 1998-2001 state-level data. Am J Manag Care 2003;9(Spec No 1, SP1):SP13–SP24
46 Wu VY, Shen YC, Yun MS, Melnick G. Decomposition of the drivers of the U.S. hospital spending growth, 2001-2009. BMC Health Serv Res 2014;14(01):230
47 Jann B. NLCHECK: Stata Module to Check Linearity Assumption after Model Estimation. Statistical Software Components S456968. Boston College of Economics; 2008
48 American Hospital Association. Rural Report: Challenges Facing Rural communities and the Roadmap to Ensure Local Access to High-quality, Affordable Care. 2019 Accessed May 25, 2021 at: https://www.aha.org/system/files/2019-02/rural-report-2019.pdf
49 Everson J, Rubin JC, Friedman CP. Reconsidering hospital EHR adoption at the dawn of HITECH: implications of the reported 9% adoption of a "basic" EHR. J Am Med Inform Assoc 2020;27(08):1198–1205
50 Centers for Medicare and Medicaid Services. Promoting Interoperability Programs. 2021 Accessed January 20, 2021 at: https://www.cms.gov/Regulations-and-Guidance/Legislation/EHRIncentivePrograms
51 Greenberg AJ, Haney D, Blake KD, Moser RP, Hesse BW. Differences in access to and use of electronic personal health information between rural and urban residents in the United States. J Rural Health 2018;34(Suppl 1):s30–s38
52 Economic Research Service (ERS)Rural Urban Continuum Codes. 2022 Accessed March 16, 2022 at: https://www.ers.usda.gov/data-products/rural-urban-continuum-codes.aspx