Effect of Electronic Health Records on Health Care Costs: Longitudinal Comparative Evidence From Community Practices

Julia Adler-Milstein, PhD; Claudia Salzberg, MSc; Calvin Franz, PhD; E. John Orav, PhD; Joseph P. Newhouse, PhD; and David W. Bates, MD, MSc

Background: The United States is aiming to achieve nationwide adoption of electronic health records (EHRs) but lacks robust empirical evidence to anticipate the effect on health care costs.

Objective: To assess short-term cost savings from community-wide adoption of ambulatory EHRs.

Design: Longitudinal trial with parallel control group.

Setting: Natural experiment in which 806 ambulatory clinicians across 3 Massachusetts communities adopted subsidized EHRs. Six matched control communities applied but were not selected to participate.

Patients: 47 979 intervention patients and 130 603 control patients.

Measurements: Monthly standardized health care costs from commercial claims data from January 2005 to June 2009, including total cost, inpatient cost, and ambulatory cost and its subtypes (pharmacy, laboratory, and radiology). Projected savings per member per month (PMPM), excluding EHR adoption costs.

Results: Ambulatory EHR adoption did not impact total cost (pre- to postimplementation difference in monthly trend change, −0.30 percentage point; $P = 0.135$), but the results favored savings (95% CI, \$21.95 PMPM in savings to \$1.53 PMPM in higher costs). It slowed ambulatory cost growth (difference in monthly trend change, −0.35 percentage point; $P = 0.012$); projected ambulatory savings were \$4.69 PMPM (CI, \$8.45 to \$1.09 PMPM) (3.10% of total PMPM cost). Ambulatory radiology costs decreased (difference in monthly trend change, −1.61 percentage points; $P < 0.001$), with projected savings of \$1.61 PMPM (1.07% of total PMPM cost).

Limitations: Intervention communities were not randomly selected and received implementation support, suggesting that results may represent a best-case scenario. Confounding is possible.

Conclusion: Using commercially available EHRs in community practices seems to modestly slow ambulatory cost growth. Broader changes in the organization and payment of care may prompt clinicians to use EHRs in ways that result in more substantial savings.

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For author affiliations, see end of text.

The United States is undertaking a large-scale effort to increase the use of electronic health records (EHRs). The centerpiece of the 2009 Health Information Technology for Economic and Clinical Health (HITECH) Act is \$27 billion in incentives to encourage physicians and hospitals to adopt and use EHRs according to federally defined "meaningful use" criteria (1, 2). The legislation was motivated by the expectation that EHRs would lead to higher-quality, lower-cost care by avoiding inefficiencies, inappropriate care, and medical errors (3–6).

The expectation that EHRs will lower health care costs has come under scrutiny. They could do so by several means: Easier access to patient medical records could limit unnecessary office visits by enabling physicians to deal with clinical issues by phone, electronic prescribing could prevent adverse drug events and the associated cost, and access to previous diagnostic test results could decrease duplicative testing. However, many question whether EHR functions, such as test result viewing and computerized order entry, will reduce costs or drive them higher by making information more accessible and easing the ordering processes (7–9). Costs could also increase if EHR use reduces rejected claims and helps justify higher reimbursement (10).

Available empirical evidence has not yet resolved the debate. Evaluations done by a few leading institutions point to health care cost savings (11–14). However, the EHRs they evaluated incorporated advanced functionalities optimized for their clinical setting, such as clinical decision support that reduced costs by guiding physicians away from inappropriate tests and procedures (15, 16). Recent studies, which failed to show savings, focus more narrowly on how EHRs impact the cost of discrete clinical encounters or care delivered by individual physicians or organizations (7–9). Although EHR advocates argue that savings will come from "network" effects of EHRs when all practices across the community become wired, we lack supporting evidence.

A Massachusetts experiment enabled us to test the hypothesis that community-wide EHR adoption would result in cost savings. The Massachusetts eHealth Collaborative (MAeHC), launched in 2006, helped 3 communities widely deploy ambulatory EHRs. The experiment, which included subsidized EHR adoption and provision of technical aid, served as a model for the HITECH Act (17). Because participating providers reported using EHRs in similar ways to the initial meaningful use criteria (for ex-

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Context

Data are lacking to support speculation that the increase in the use of electronic health records in the United States will result in cost savings by increasing efficiency.

Contribution

This analysis of implementation of EHRs by 806 ambulatory care clinicians in 3 Massachusetts communities did not identify statistically significant cost savings, but the results suggest that EHRs might slow cost increases.

Caution

Pilot communities were not selected at random. Differences between intervention and control communities could contribute to observed findings.

Implication

This pilot study suggests that implementation of EHRs may be associated with modest reduction in growth of health care costs.

—The Editors

ample, entering medication orders and test result viewing), the MAeHC experiment offers timely data on how the federal meaningful use program may impact costs in the short-term.

We compared health care costs for patients who received most of their care from providers (such as individual clinicians) who adopted EHRs in the experimental pilot communities with those for patients in matched control communities that applied, but were not selected, to be part of the pilot. We evaluated whether the intervention changed the monthly cost trend from the 15 months before implementation to the 18 months after implementation. We examined overall cost and cost in prespecified categories (ambulatory pharmacy, laboratory, and radiology), which evidence suggests are most sensitive to EHR use (11, 12, 14, 16). All cost measures were derived from claims data and standardized (that is, a dollar weighted value of utilization) to capture a societal perspective.

Methods

Setting and Intervention

The MAeHC was established to administer a large-scale pilot of EHRs in the ambulatory setting (18–21). Three communities were selected from 32 in Massachusetts that applied to serve as pilot sites. The MAeHC purposely selected those with heterogeneous populations and a high likelihood of broad adoption to assess the resulting effect on cost and quality. In the 3 communities, 167 practices with a relationship to their community hospital were eligible, 86% of which participated (22). These practices were largely representative of those in the state (23). Intervention communities were enthusiastic about participating because of the subsidized EHRs and implementation support, and neither the MAeHC nor the communities pursued specific quality improvement or cost reduction targets.

Each intervention community evaluated and approved up to 4 commercially available EHR systems from which participating practices could choose. The most common systems were from Allscripts (Chicago, Illinois), GE Centricity (Little Chalfont, United Kingdom), eClinicalWorks (Westborough, Massachusetts), and NextGen (Horsham, Pennsylvania) (20). Although functionality varied by system and practice, most providers used EHRs in ways that were consistent with the priorities of stage 1 meaningful use and were expected to reduce costs: capturing core clinical data electronically, entering medication orders, and viewing tests results (1, 17) (**Table 1**).

System costs and implementation support were almost fully covered by the MAeHC. Implementation began in March 2006 and ended in December 2007. The preimplementation analytic period spanned the 15 months before March 2006, and the postimplementation analytic period spanned 18 months beginning in January 2008.

The study was approved by the Institutional Review Board at Partners HealthCare in Boston.

Data

Two commercial insurers that collectively cover most of the private market in Massachusetts provided complete medical and pharmacy claims histories from the analytic period (January 2005 to June 2009) for all members who lived or received care in an intervention or a control community.

Selection of Control Patients

To maximize comparability of the patient populations assigned to intervention and control communities, we matched communities, matched providers within communities, and selected patients receiving most of their care from matched providers.

To help ensure shared interest in EHR adoption and associated unobserved characteristics, we matched 2 control communities to each intervention community from the pool of applicants. We used several community characteristics to select control communities. We first calculated the standardized difference for each baseline characteristic (that is, the difference between each intervention community and potential control community characteristic, divided by the pooled SD of that characteristic across communities) (24, 25). Then, we squared and summed standardized differences across all characteristics. The 2 control communities with the smallest total standardized differences relative to an intervention community were chosen. Available survey data (26) confirmed that no control community had widespread EHR adoption at the outset of the analytic period.

Control providers who would have probably participated in the pilot had their community been selected were identified. First, because not all types of providers were eligible to participate (for example, hospitalists), we used provider specialty data from insurers' directories to identify which specialties had no providers participating in intervention communities and removed them from control communities. Second, because not all eligible providers chose to participate, we estimated a logistic regression model for each intervention community by using observed characteristics that best differentiated their participating providers from nonparticipating providers. We then applied the model to providers in their matched control communities to predict the probability that a given control provider would have been included in the pilot had his or her community been chosen. We selected control providers with the highest probability scores and took the same percentage of providers from control communities as were adopters in the matched intervention community.

Finally, patients were assigned to 1 of the 9 communities if more than half of their ambulatory spending (dollar amount) and ambulatory claims (number of claims, regardless of amount) were billed by intervention or matched control providers in that community (27).

Outcome Measures

To assess the effect of the intervention on total cost and capture any spillover effects from broad community adoption, we examined all care received by patients assigned to an intervention or a control community, not the subset of care delivered by intervention and matched control providers. This mirrors the early experience under the HITECH Act in which patients receive care from several providers, only some of whom have adopted EHRs.

We created cost measures that reflect a societal perspective by applying a standardized cost from 2009 Medicare fee schedules to each claim based on the diagnosis-related group or Current Procedural Terminology codes. By using a standardized fee schedule that holds payments for a given service constant across providers and insurers over time, the resulting cost measures capture changes in utilization and not changes in reimbursement rates that could vary by community (28, 29).

We created a measure of total cost for patients in each month in which they were insured and then split it into inpatient and ambulatory costs. Because the intervention occurred in the ambulatory setting, we further broke down ambulatory cost into pharmacy, laboratory, radiology, and other.

Analytic Models

For each measure, we fitted a longitudinal regression model by using each patient's aggregate monthly cost as the unit of analysis. Time was incorporated by means of a piecewise regression model to account for potential change in trend. We evaluated the effect of the intervention by determining whether the linear trend in the preimplementation period (January 2005 to March 2006) differed from the linear trend in the postimplementation period (January 2008 to June 2009) for patients assigned to intervention communities compared with patients assigned to control communities. The treatment, EHR adoption, is considered cost-saving if the pre- to postimplementation change in cost trend decreases more (absolute reduction) or does not increase as quickly (slower growth in upward trajectory) for intervention patients compared with control patients (**Figure 1** of the **Supplement**, available at www.annals.org).

Because of the skewness of individual medical spending, we assumed that the outcomes followed a gamma distribution and fit a marginal regression model with a log link between the outcome and the predictor variables. This was chosen over a log-normal approach to enhance interpretability of the coefficients and because of its improved efficiency based on the Park residual diagnostics (30). We accounted for correlation over time and between patients seen by the same provider through the residual terms; moreover, we used a marginal correlation approach implemented via PROC GENMOD in SAS, version 9.3 (SAS Institute, Cary, North Carolina). The marginal model enables a straightforward interpretation of model effects as the effect of EHR implementation across intervention providers (31) and allows for robust SEs by estimating the correlation structure directly from model residuals. We ex-

Table 1. **MAeHC Pilot Providers' Self-Reported EHR Use in 2009**

EHR Use	Reporting Use "Most or All of the Time," %	Related Stage 1 Meaningful Use Measure
Electronic problem list	65	Maintain up-to-date problem list of current and active diagnoses
Electronic medication lists of what each patient receives	80	Maintain active medication list
Document allergies in EHR	94	Maintain active medication allergy list
Transmit prescriptions to pharmacy electronically or via fax	76	Generate and transmit permissible prescriptions electronically
Generate computerized medication prescriptions with or without decision support	81	CPOE for medication orders
Generate computerized medication prescriptions with decision support*	60	Implement drug–drug and drug–allergy interaction checks
Laboratory tests results	78	NA
Radiology tests results	74	NA

CPOE = computerized physician order entry; EHR = electronic health record; MAeHC = Massachusetts eHealth Collaborative; NA = not applicable.
* Includes drug interaction or allergy alerts.

Table 2. **Analytic Sample and Provider Characteristics**

Variable	Value
Analytic sample, *n*	
Communities	
Intervention	3
Control	6
Providers*	
Intervention	806
Control	1597
Patients	
Intervention	47 979
Control	130 603
Provider characteristics, %	
Sole proprietor	
Intervention	7
Control	9
Primary care	
Intervention	41
Control	49
Specialty†	
Orthopedic surgery	
Intervention	4
Control	5
Cardiology	
Intervention	4
Control	3
General surgery	
Intervention	3
Control	3

* Includes clinicians.
† We report the 3 most prevalent non–primary care specialties. Specialties that are not represented in the study findings (because there were no intervention providers of that specialty) include anatomical and clinical pathology, chiropractic, diagnostic radiology, hospital-based emergency medicine, ophthalmology, oral and maxillofacial surgery, physical therapy, and radiology.

ponentiated model coefficients to interpret results as the monthly percentage change in costs during the pre- and postimplementation periods.

Our models also adjusted for seasonal trends and the following patient demographic characteristics, which may change over time in our sample: age, sex, type of coverage (for example, HMO), and Charlson comorbidity index conditions. We decided a priori to estimate each model twice—once for all patients and once limited to the subset of patients with 1 or more chronic diseases because we hypothesized that the intervention effect may differ for a sicker population. Subsequently, we examined results for HMO and non-HMO patients. Although HMO patients' utilization may be better managed overall, limiting the potential opportunity for further reduction from EHR adoption, providers may be more motivated to use newly adopted EHRs to reduce costs if they can collect the resulting savings.

To better understand the magnitude of our effect estimates, we predicted costs from our models at 3 time points: start of the preimplementation period, start of the implementation period, and end of the postimplementation period. We also generated savings projections by calculating the average projected cost per member per month (PMPM) over the 18-month postimplementation period under 2 scenarios: cost changes based on the experience in the intervention communities and cost changes based on the experience in the control communities. The difference between the former and the latter represents the cost effect of the intervention.

Role of the Funding Source

Our funding source, the MAeHC, provided the names of participating providers and applicant communities, but was not otherwise involved in the design, conduct, or analysis of the study and publication decisions.

RESULTS

Sample

Our analytic sample included 4 812 412 patient-month observations from 47 979 intervention patients and 130 603 control patients who received most of their care from 806 intervention providers or 1597 matched control providers (**Tables 2** and **3**).

Total Cost

Total cost increased 0.78 absolute percentage point in intervention and 1.09 absolute percentage points in control communities (difference in change in trend, −0.30 percentage point [95% CI, −0.70 to 0.09 percentage points]; P = 0.135) (**Table 4**). Associated predicted PMPM costs at the start of the preimplementation period were $151 among intervention patients and $155 among

Table 3. **Patient Characteristics***

Characteristic	Preimplementation Period†	Postimplementation Period‡	Change
Mean age, *y*			
Intervention	32.76	29.06	−3.70
Control	32.81	29.17	−3.64
Male			
Intervention	47.19	46.88	−0.31
Control	46.39	46.12	−0.27
≥2 chronic diseases			
Intervention	8.79	7.66	−1.13
Control	7.12	6.07	−1.05
Chronic disease prevalence§			
COPD			
Intervention	21.62	20.74	−0.88
Control	16.90	15.77	−1.13
Diabetes			
Intervention	7.15	6.12	−1.03
Control	6.23	5.43	−0.80
Heart failure‖			
Intervention	2.92	2.42	−0.50
Control	2.85	2.27	−0.58

COPD = chronic obstructive pulmonary disease.
* Values are percentages unless otherwise indicated.
† From January 2005 to March 2006.
‡ From January 2008 to June 2009.
§ We report the 3 most prevalent chronic diseases within the Charlson comorbidity index.
‖ Includes myocardial infarction and congestive heart failure.

Table 4. **Pre- and Postimplementation Cost Trends and Difference in Change in Trend**

Cost	Monthly Preimplementation Trend, %	Monthly Postimplementation Trend, %	Difference in Change in Trend (95% CI), *percentage points*	*P* Value
Total*				
Intervention	0.32	1.10	−0.30 (−0.70 to 0.09)	0.135
Control	0.14	1.23		
Inpatient				
Intervention	−0.59	0.48	0.18 (−2.51 to 2.94)	0.90
Control	0.30	1.20		
Ambulatory				
Total				
Intervention	0.41	1.12	−0.35 (−0.63 to −0.08)	0.012
Control	0.14	1.20		
Pharmacy				
Intervention	0.15	0.63	−0.35 (−0.84 to 0.14)	0.167
Control	0.04	0.86		
Laboratory				
Intervention	0.73	1.32	−0.38 (−0.79 to 0.02)	0.061
Control	0.29	1.27		
Radiology				
Intervention	1.03	0.60	−1.61 (−2.26 to −0.95)	<0.001
Control	−0.25	0.94		
Other				
Intervention	0.30	1.39	−0.11 (−0.42 to 0.20)	0.50
Control	0.09	1.28		

* Includes inpatient and ambulatory costs.

control patients (**Appendix Table 1**, available at www.annals.org). Fifteen months later, at the start of implementation, these had increased to $158 PMPM for both groups. By the end of the postimplementation period, projected PMPM costs were $173 among intervention patients compared with $179 among control patients.

Table 5. **Pre- and Postimplementation Cost Trends and Difference in Change in Trend for Patients With Chronic Diseases Only**

Cost	Monthly Preimplementation Trend, %	Monthly Postimplementation Trend, %	Difference in Change in Trend (95% CI), *percentage points*	*P* Value
Total*				
Intervention	0.29	0.85	−0.14 (−0.73 to 0.45)	0.66
Control	0.38	1.08		
Inpatient				
Intervention	−1.09	0.83	1.44 (−1.60 to 4.48)	0.34
Control	0.54	1.02		
Ambulatory				
Total				
Intervention	0.54	0.77	−0.41 (−0.86 to 0.04)	0.077
Control	0.38	1.02		
Pharmacy				
Intervention	0.40	0.25	−0.51 (−1.22 to 0.20)	0.164
Control	0.34	0.70		
Laboratory				
Intervention	0.94	1.41	−0.28 (−0.95 to 0.39)	0.43
Control	0.57	1.32		
Radiology				
Intervention	1.13	0.48	−1.62 (−2.58 to −0.66)	0.001
Control	−0.12	0.85		
Other				
Intervention	0.38	1.21	−0.05 (−0.36 to 0.46)	0.80
Control	0.50	1.28		

* Includes inpatient and ambulatory costs.

Table 6. **Financial Effect and Cost for All Patients**

Variable	Total	Inpatient	Ambulatory Cost				
			Total*	Pharmacy	Laboratory	Radiology*	Other
Mean preimplementation PMPM cost in intervention community, $	151.13	29.21	121.93	64.13	4.15	8.88	44.77
Postimplementation PMPM cost, $							
Assuming trend in intervention community	167.95	30.09	135.77	68.11	4.71	9.40	51.17
Assuming trend in control community	173.09	30.58	140.46	70.38	4.89	11.01	51.68
PMPM savings (lower, upper bounds)†	5.14 (21.95, −1.53)	0.49 (6.33, −10.05)	4.69 (8.45, 1.09)	2.27 (5.45, −1.03)	0.18 (0.36, −0.01)	1.61 (2.20, 0.98)	0.51 (2.07, −1.02)
Savings, %							
Based on mean PMPM cost per category‡	3.40	1.68	3.85	3.54	4.34	18.13	1.14
Based on mean PMPM total cost (lower, upper bounds)§	3.40 (15.00, −1.01)	0.32 (4.19, −6.65)	3.10 (5.59, 0.72)	1.50 (3.61, −0.68)	0.12 (0.24, −0.01)	1.07 (1.46, 0.65)	0.34 (1.37, −0.67)

PMPM = per member per month.
* Statistically significant ($P < 0.05$) difference in change in trend.
† Derived from the value of assuming a trend in the control community minus the value of assuming a trend in the intervention community.
‡ The denominators are the values in the first row.
§ The denominator is $151.13.

Subtypes of Cost

Whereas inpatient cost did not reflect a statistically significant pre- to postimplementation difference (absolute difference in monthly trend change, 0.18 percentage point [CI, −2.51 to 2.94 percentage points]; $P = 0.90$), ambulatory costs increased more slowly in intervention than control communities (absolute difference in monthly trend change, −0.35 percentage point [CI, −0.63 to −0.08 percentage points]; $P = 0.012$) (**Table 4**). Ambulatory pharmacy, laboratory, and radiology costs all favored intervention patients, but only radiology cost was statistically significant. The estimated absolute difference in monthly trend change was −0.35 percentage point for pharmacy costs (CI, −0.84 to 0.14 percentage points; $P = 0.167$) and −0.38 percentage point for laboratory costs (CI, −0.79 to 0.02 percentage points; $P = 0.061$). Radiology costs exhibited the largest difference of −1.61 percentage points (CI, −2.26 to −0.95 percentage points; $P < 0.001$); it was the only outcome with an absolute decrease in monthly cost growth in the pre- to postimplementation periods for intervention patients (from 1.03% to 0.60%), whereas the cost trajectory increased among control patients.

Costs Among Subgroups

The 25% of the population (12 139 intervention patients and 28 813 control patients) with chronic diseases showed no statistically significant pre- to postimplementation difference in total cost (absolute difference in monthly trend change, −0.14 percentage point [CI, −0.73 to 0.45 percentage points]; $P = 0.66$) or for inpatient or ambulatory cost. For ambulatory radiology, monthly cost growth decreased (absolute difference in trend change, −1.62 percentage points [CI, −2.58 to −0.66 percentage points]; $P = 0.001$) (**Table 5**).

Among HMO patients, who constituted most of the population ($n = 102\ 332$ [57%]), we found evidence for savings in total and ambulatory costs (**Appendix Table 2**, available at www.annals.org). Pharmacy, laboratory, and radiology costs increased more slowly among HMO patients in the intevention communities than in the control communities. In contrast, among non-HMO patients, the pilot resulted in only ambulatory radiology savings (**Appendix Table 3**, available at www.annals.org).

Estimated Cost Effect

Relative to the average PMPM total cost of $151.13 across the 3 intervention communities in the preimplementation period, the $5.14 in projected average PMPM savings over the 18 months after implementation represents 3.40% savings (**Table 6**). The associated CI around this point estimate is 15.00% ($21.95) to −1.01% (−$1.53). Ambulatory cost accounts for most of the savings, with $4.69 in projected PMPM savings (3.10% of total PMPM cost [CI, 5.59% to 0.72%]). Savings in radiology were $1.61 PMPM (1.07% of total PMPM cost [CI, 1.46% to 0.65%]) (**Table 6**). Assuming $5.14 PMPM savings for the 47 979 intervention patients, it would take approximately 7 years to recoup the projected 5-year adoption cost in the pilot communities of $130 822 per provider (10).

Discussion

We used a natural experiment in community practices to address an important gap in the literature on the effect of EHRs on health care costs. Our study offers robust evidence on the likely short-term effect of the federal policy effort to promote meaningful use of EHRs. The setting was typical of practices that deliver ambulatory care in the United States. Practices were mostly small, with a mix of primary and specialty care, and used commercially available EHRs to perform the core clinical tasks that are required of physicians in the first stage of meaningful use. In the 18 months after adoption, we saw ambulatory cost savings of 3% PMPM and reductions in ambulatory radiology cost. If sustained for a sufficiently long period, these could translate to substantial savings.

Pilot providers reported that viewing laboratory and radiology test results were among the most common uses of their EHRs (**Table 1**). Easier access to previous results may have prompted providers to order fewer tests, particularly in radiology. Reducing these ancillary costs may have been facilitated by the fact that most ordering providers would not incur the associated lost revenue. Our failure to find a statistically significant reduction in total cost may be explained by providers not using EHRs in more advanced ways that would improve patient health status, thereby avoiding hospitalizations and other high-cost episodes. The disruption caused by EHR adoption could have made it difficult for providers to learn how to use EHRs to monitor population health, better coordinate care, or engage in more sophisticated use.

Studies examining the effect of ambulatory EHRs on specific types of costs report mixed findings. Recently, a national cross-sectional study found that electronic availability of test results was associated with an increased likelihood of ordering diagnostic tests among physicians (7), but reductions in radiology and clinical laboratory services were seen after EHR adoption in 2 Kaiser Permanente regions, with a 14% decrease in the use of radiology services in 1 region (14). A small controlled trial also found reductions in radiology and laboratory use when physicians were shown past test results electronically (13). Our study provides more generalizable evidence for savings in these 2 domains and extends the literature by examining the effect on total cost.

Our study has several limitations. Although we used many strategies to improve comparability (limiting control communities to those that applied to be pilot sites, matching control and intervention communities on a broad range of characteristics, narrowing providers within control communities to those with characteristics similar to intervention providers, adjusting for differences in member demographic characteristics, and examining whether the change in cost trend differed), we may not have controlled for all confounding, including temporal trends that could have differentially affected utilization in specific communities. In addition, pilot communities were not randomly selected. The MAeHC intentionally chose communities that were heterogeneous and had a strong likelihood of successful EHR adoption, suggesting that our results may represent a best-case scenario.

Our data capture costs incurred in the private market and by relatively young patients; therefore, effect sizes may be larger in Medicare or Medicaid populations. Although we determined that control communities had low levels of EHR adoption at the start of the pilot, some could have increased this on their own after they were not selected to participate, which could have led to an underestimate in savings. The substantial resources devoted to implementing EHRs in practices in the intervention communities were not netted out of savings estimates. Because similar resources are unlikely to be available outside the pilot, our findings may overestimate the savings resulting from community-based EHR adoption. Finally, we were not able to evaluate the clinical appropriateness of changes in utilization that we saw.

In summary, we examined a large, ambulatory EHR pilot to assess the effect on short-term health care costs. Adoption of EHRs resulted in ambulatory cost savings, with particularly strong evidence for savings in radiology. Reducing health spending by the magnitude that we observed would result in substantial savings if sustained over several years. Larger savings are possible if providers have incentives to deliver more efficient care. Efforts to reform financing and delivery of care alongside greater use of EHRs may focus clinicians' attention on how best to leverage their EHR to achieve savings and help realize the full benefit from our large national investment in EHRs.

From University of Michigan, Ann Arbor, Michigan; Brigham and Women's Hospital and Harvard Medical School and Harvard School of Public Health, Boston, Massachusetts; Eastern Research Group, Lexington, Massachusetts; and Harvard Kennedy School, Cambridge, Massachusetts.

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Requests for Single Reprints: Julia Adler-Milstein, PhD, University of Michigan, School of Information, 4376 North Quad, 105 South State Street, Ann Arbor, MI 48109; e-mail, juliaam@umich.edu.

Current author addresses and author contributions are available at www.annals.org.

References

1. **Blumenthal D, Tavenner M.** The "meaningful use" regulation for electronic health records. N Engl J Med. 2010;363:501-4. [PMID: 20647183]
2. **DesRoches CM, Campbell EG, Rao SR, Donelan K, Ferris TG, Jha A, et al.** Electronic health records in ambulatory care—a national survey of physicians. N Engl J Med. 2008;359:50-60. [PMID: 18565855]
3. **Blumenthal D, Glaser JP.** Information technology comes to medicine. N Engl J Med. 2007;356:2527-34. [PMID: 17568035]
4. **Blumenthal D.** Stimulating the adoption of health information technology. N Engl J Med. 2009;360:1477-9. [PMID: 19321856]
5. **Hillestad R, Bigelow J, Bower A, Girosi F, Meili R, Scoville R, et al.** Can electronic medical record systems transform health care? Potential health benefits, savings, and costs. Health Aff (Millwood). 2005;24:1103-17. [PMID: 16162551]
6. **Walker J, Pan E, Johnston D, Adler-Milstein J, Bates DW, Middleton B.** The value of health care information exchange and interoperability. Health Aff (Millwood). 2005;Suppl Web Exclusives:W5-10-W5-18. [PMID: 15659453]
7. **McCormick D, Bor DH, Woolhandler S, Himmelstein DU.** Giving office-based physicians electronic access to patients' prior imaging and lab results did not deter ordering of tests. Health Aff (Millwood). 2012;31:488-96. [PMID: 22392659]
8. **Sidorov J.** It Ain't Necessarily So: The Electronic Health Record And The Unlikely Prospect Of Reducing Health Care Costs. Health Aff (Millwood). 2006;25:1079-85. [PMID: 16835189]
9. **Himmelstein DU, Woolhandler S.** Hope and hype: predicting the impact of electronic medical records. Health Aff (Millwood). 2005;24:1121-3. [PMID: 16162553]
10. **Adler-Milstein J, Green CE, Bates DW.** A survey analysis suggests that electronic health records will yield revenue gains for some practices and losses for many. Health Aff (Millwood). 2013;32:562-70. [PMID: 23459736]
11. **Tierney WM, Miller ME, McDonald CJ.** The effect on test ordering of informing physicians of the charges for outpatient diagnostic tests. N Engl J Med. 1990;322:1499-504. [PMID: 2186274]
12. **Wang SJ, Middleton B, Prosser LA, Bardon CG, Spurr CD, Carchidi PJ, et al.** A cost-benefit analysis of electronic medical records in primary care. Am J Med. 2003;114:397-403. [PMID: 12714130]
13. **Tierney WM, McDonald CJ, Martin DK, Rogers MP.** Computerized display of past test results. Effect on outpatient testing. Ann Intern Med. 1987;107:569-74. [PMID: 3631792]
14. **Garrido T, Jamieson L, Zhou Y, Wiesenthal A, Liang L.** Effect of electronic health records in ambulatory care: retrospective, serial, cross sectional study. BMJ. 2005;330:581. [PMID: 15760999]
15. **Congressional Budget Office.** Evidence on the Costs and Benefits of Health Information Technology. Washington, DC: Congressional Budget Office; 2008. Accessed at www.cbo.gov/sites/default/files/cbofiles/ftpdocs/91xx/doc9168/05-20-healthit.pdf on 8 April 2013.
16. **Chaudhry B, Wang J, Wu S, Maglione M, Mojica W, Roth E, et al.** Systematic review: impact of health information technology on quality, efficiency, and costs of medical care. Ann Intern Med. 2006;144:742-52. [PMID: 16702590]
17. **Tripathi M.** National Committee on Vital and Health Statistics. Measuring Meaningful Use. Waltham, MA: Massachusetts eHealth Collaborative; 2009. Accessed at www.ncvhs.hhs.gov/090429p10c.pdf on 8 April 2013.
18. **Fleurant M, Kell R, Jenter C, Volk LA, Zhang F, Bates DW, et al.** Factors associated with difficult electronic health record implementation in office practice. J Am Med Inform Assoc. 2012;19:541-4. [PMID: 22249965]
19. **Goroll AH, Simon SR, Tripathi M, Ascenzo C, Bates DW.** Community-wide implementation of health information technology: the Massachusetts eHealth Collaborative experience. J Am Med Inform Assoc. 2009;16:132-9. [PMID: 18952937]
20. **Mostashari F, Tripathi M, Kendall M.** A tale of two large community electronic health record extension projects. Health Aff (Millwood). 2009;28:345-56. [PMID: 19275989]
21. **Tripathi M, Delano D, Lund B, Rudolph L.** Engaging patients for health information exchange. Health Aff (Millwood). 2009;28:435-43. [PMID: 19276000]
22. **Fleurant M, Kell R, Love J, Jenter C, Volk LA, Zhang F, et al.** Massachusetts e-Health Project increased physicians' ability to use registries, and signals progress toward better care. Health Aff (Millwood). 2011;30:1256-64. [PMID: 21734198]
23. **Simon SR, Kaushal R, Jenter CA, Volk LA, Burdick E, Poon EG, et al.** Readiness for electronic health records: comparison of characteristics of practices in a collaborative with the remainder of Massachusetts. Inform Prim Care. 2008; 16:129-37. [PMID: 18713529]
24. **Rubin DB.** Using multivariate matched sampling and regression adjustment to control bias in observational studies. J Am Stat Assoc. 1979;74(366a):318-28.
25. **Rosenbaum P.** Design of Observational Studies. New York: Springer; 2009.
26. **Simon SR, Kaushal R, Cleary PD, Jenter CA, Volk LA, Orav EJ, et al.** Physicians and electronic health records: a statewide survey. Arch Intern Med. 2007;167:507-12. [PMID: 17353500]
27. **Steinwachs DM, Stuart ME, Scholle S, Starfield B, Fox MH, Weiner JP.** A comparison of ambulatory Medicaid claims to medical records: a reliability assessment. Am J Med Qual. 1998;13:63-9. [PMID: 9611835]
28. **Medicare Payment Advisory Commission.** Report to Congress: Measuring Regional Variation in Service Use. Washington, DC: Medicare Payment Advisory Commission; 2009. Accessed at www.medpac.gov/documents/Dec09_RegionalVariation_report.pdf on 8 April 2013.
29. **Medicare Payment Advisory Commission.** Report to the Congress: Regional Variation in Medicare Service Use. Washington, DC: Medicare Payment Advisory Commission; 2011. Accessed at www.medpac.gov/documents/Jan11_RegionalVariation_report.pdf on 8 April 2013.
30. **Manning WG, Mullahy J.** Estimating log models: to transform or not to transform? J Health Econ. 2001;20:461-94. [PMID: 11469231]
31. **Fitzmaurice GM, Laird NM, Ware JH.** Applied Longitudinal Analysis. 2nd ed. New York: J Wiley; 2011.

Current Author Addresses: Dr. Adler-Milstein: University of Michigan, School of Information, 4376 North Quad, 105 South State Street, Ann Arbor, MI 48109.
Ms. Salzberg and Drs. Orav and Bates: Brigham and Women's Hospital, Division of General Internal Medicine and Primary Care, 1620 Tremont Street, OBC-3, Boston, MA 02120.
Dr. Franz: Eastern Research Group, Inc., 110 Hartwell Avenue, Lexington, MA 02421-3136.
Dr. Newhouse: Harvard Medical School, Department of Health Care Policy, 180 Longwood Avenue, Boston, MA 02115.

Author Contributions: Conception and design: J. Adler-Milstein, C. Franz, J.P. Newhouse, D.W. Bates.
Analysis and interpretation of the data: J. Adler-Milstein, C. Salzberg, C. Franz, E.J. Orav, J.P. Newhouse.
Drafting of the article: J. Adler-Milstein, C. Salzberg, E.J. Orav.
Critical revision of the article for important intellectual content: J. Adler-Milstein, C. Franz, E.J. Orav, J.P. Newhouse, D.W. Bates.
Final approval of the article: J. Adler-Milstein, E.J. Orav, J.P. Newhouse, D.W. Bates.
Statistical expertise: J. Adler-Milstein, E.J. Orav.
Obtaining of funding: J. Adler-Milstein, D.W. Bates.
Administrative, technical, or logistic support: J. Adler-Milstein, D.W. Bates.
Collection and assembly of data: J. Adler-Milstein, C. Salzberg.

Appendix Table 1. **Projected Costs at Start of Preimplementation Period, Start of Implementation, and End of Postimplementation Period**

Projected Cost	Intervention, $	Control, $
Total		
January 2005	151.13	154.66
March 2006	157.71	157.90
June 2009	172.93	178.56
Inpatient		
January 2005	29.21	31.11
March 2006	27.17	32.93
June 2009	29.97	35.08
Ambulatory		
Total*		
January 2005	121.93	123.84
March 2006	128.65	126.30
June 2009	141.02	143.44
Pharmacy		
January 2005	64.13	62.17
March 2006	65.22	62.42
June 2009	65.07	66.68
Laboratory		
January 2005	4.15	4.32
March 2006	4.86	4.67
June 2009	6.07	5.84
Radiology*		
January 2005	8.88	11.41
March 2006	10.59	10.99
June 2009	10.79	12.94
Other		
January 2005	44.77	45.84
March 2006	47.04	46.52
June 2009	55.69	53.68

* Statistically significant ($P < 0.05$) difference in change in trend.

Appendix Table 2. **Pre- and Postimplementation Cost Trends and Difference in Change in Trend for HMO Patients**

Cost	Monthly Preimplementation Trend, %	Monthly Postimplementation Trend, %	Difference in Change in Trend (95% CI), *percentage points*	*P* Value
Total*				
Intervention	0.62	1.08	−0.47 (−0.92 to −0.02)	0.038
Control	0.34	1.27		
Inpatient				
Intervention	0.24	0.45	−0.66 (−3.72 to 2.40)	0.67
Control	0.54	1.41		
Ambulatory				
Total				
Intervention	0.61	1.10	−0.44 (−0.75 to −0.13)	0.008
Control	0.32	1.25		
Pharmacy				
Intervention	0.70	0.59	−0.53 (−1.08 to 0.02)	0.052
Control	0.56	0.98		
Laboratory				
Intervention	0.73	1.19	−0.49 (−0.01 to −0.02)	0.039
Control	0.35	1.30		
Radiology				
Intervention	1.05	0.64	−1.67 (−2.41 to −0.93)	<0.001
Control	−0.23	1.03		
Other				
Intervention	0.29	1.38	−0.11 (−0.46 to 0.24)	0.53
Control	0.08	1.28		

* Includes inpatient and ambulatory costs.

Appendix Table 3. **Pre- and Postimplementation Cost Trends and Difference in Change in Trend for Non-HMO Patients**

Cost	Monthly Preimplementation Trend, %	Monthly Postimplementation Trend, %	Difference in Change in Trend (95% CI), *percentage points*	*P* Value
Total*				
Intervention	−0.64	1.16	0.10 (−0.76 to 0.96)	0.82
Control	−0.62	1.08		
Inpatient				
Intervention	−3.07	0.61	2.55 (−2.86 to 7.96)	0.34
Control	−0.53	0.60		
Ambulatory				
Total				
Intervention	−0.27	1.13	−0.20 (−0.73 to 0.33)	0.46
Control	−0.56	1.04		
Pharmacy				
Intervention	−1.49	0.69	0.11 (−1.05 to 1.27)	0.84
Control	−1.68	0.39		
Laboratory				
Intervention	0.74	1.70	−0.13 (−0.76 to 0.50)	0.67
Control	0.06	1.15		
Radiology				
Intervention	1.01	0.47	−1.59 (−2.82 to −0.36)	0.012
Control	−0.33	0.72		
Other				
Intervention	0.34	1.41	−0.14 (−0.69 to 0.41)	0.61
Control	0.09	1.30		

* Includes inpatient and ambulatory costs.