

# An empirical analysis of the financial benefits of health information exchange in emergency departments

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## ABSTRACT

**Objective** To examine the impact of health information exchange (HIE) on reducing laboratory tests and radiology examinations performed in an emergency department (ED).

**Materials and Methods** The study was conducted in an ED setting in Western New York over a period of 2 months. The care of the patients in the treatment group included an HIE query for every encounter, while the care of other patients in the control group did not include such queries. A group of medical liaisons were hired to query the medical history of patients from an HIE and provide it to the ED clinicians. Negative binomial regression was used to analyze the effects of HIE queries on the number of performed laboratory tests and radiology examinations. The log files of the HIE system since 1 year before the ED admission were used to analyze the differences in outcome measures between the 2 groups of patients.

**Results** *Ceteris paribus*, HIE usage is associated with, respectively, 52% and 36% reduction in the expected total number of laboratory tests and radiology examinations ordered per patient at the ED.

**Conclusions** The results indicate that access to additional clinical data through the HIE will significantly reduce the number of laboratory tests and radiology examinations performed in the ED settings and thus support the ongoing HIE efforts.

**Keywords:** health information exchange, duplication reduction, cost benefit analysis

In this article, the authors present the results of an empirical analysis on the effects of accessing patient information through an HIE platform on the number of the laboratory tests and radiology examinations performed in an ED in Western New York. The design of this study differentiates it from previous research. This study is focused on only one ED over a short period of time, and thus its results do not suffer from the possible *confounding effects* of unobserved factors. Moreover, the design of this study ensures that the decision to use the HIE is *exogenous* and is not driven by either patient or physician characteristics. These features allow the authors to establish a stronger causal link between querying HIE and patient outcomes.

## METHODS

### Design

This study was conducted over the period of March 27, 2014 to May 24, 2014. A group of medical liaisons led by an experienced registered nurse were trained on how to access the health information exchange (HIE) database and query clinically relevant information from patients' medical history. During the study, the medical liaisons shadowed a specific group of physicians and mid-level practitioners during all of their working shifts (including evening and night shifts) in the emergency department (ED) and provided them with relevant medical information queried from the HIE database on their tablet. The ED providers were fully informed and their consent was acquired prior the study. The medical liaisons were instructed not to interfere with the treatment process of the ED providers and only inform them about the medical information of the patients that were accessible on the HIE. The liaisons could only access the medical records of the patients who had previously provided written consent for sharing of their records on the HIE for medical treatment and research purposes.

The medical information that was accessed on the HIE included previous laboratory results, radiology examinations, hospital admissions and discharge transcripts, operative reports, and medication history.

Hereafter we use the term "*treatment group*" to refer to the patients whose care included an HIE query. Similarly, we use the term "*control group*" to refer to the patients who were treated by the clinicians who were not shadowed and whose care did not include an HIE query.

### Setting

The trial was conducted by HEALTHeLINK, the regional health information exchange organization of Western New York as a part of a series of internal quality improvement projects. The investments by the state of New York on health information technology are much higher than the national average and many of the technical interoperability problems have been resolved in this state. Moreover, an exceptionally high percentage of the medical data providers have joined HEALTHeLINK. Due to these features, the available clinical information on the HIE represents a fairly comprehensive and longitudinal record of the patients. The ED in this study is located in an average-sized suburban hospital in Western New York. The number of patient visits to the ED is comparable with the median number of visits to EDs in Western New York.

### Study Population

Seven hundred and thirty-seven patients visited ED during the shifts in which medical liaisons were present. They were selected to be included in the treatment group. Thirty-nine of the patients in this group had not provided consent and thus were excluded from the study since their medical records could not be accessed. The control group included 1275 patients who were treated by the physicians in the same

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ED during the shifts in which the medical liaisons were not present and the HIE data was not accessed. For each patient in either of the 2 groups, the de-identified HIE log files were collected since 1 year prior to the ED admission date until the discharge date from ED. Based on this de-identified dataset, age, gender, and the medical history of the patients were determined. The number of laboratory tests and the radiology examinations which were performed during the study were also measured based on this dataset. In the next section, we provide the detail descriptions of these variables.

**Measures**

We present 2 sets of analyses in which the independent and control variables are similar but the dependent variables are different. In the analysis reported in the main text, the dependent variables, respectively, represent the number of the laboratory tests or radiology examinations which are performed during the ED visit. In this analysis, dependent variables are considered count data and can only take non-negative integer values. The main independent variable of interest is the HIE. This is a dichotomous variable which is equal to 1 if the patient was in the treatment group and the HIE was queried during her treatment. The HIE is equal to zero if the patient was in control group and her care did not include an HIE query. The control variables include ED clinician as well as the patient’s age, gender, and the number of hospitalizations, laboratory tests, radiology examinations, and hospital transcriptions that were created for her since 1 year before her admission to ED during this study. The prior utilization data is not limited to the encounters at the hospital in which the study was conducted and rather includes the entire patient encounters at all of the providers of clinical data to HEALTHeLINK. Since we do not have access to the initial diagnosis codes, the prior medical history of the patients is used as a proxy for their overall medical condition. Table 1 presents descriptive statistics on patients in both treatment and control groups.

**Analysis**

We apply a negative binomial regression model to investigate the effects of querying the HIE on the number of laboratory tests and

radiology examinations which are created during a patient’s visit to the ED. We hypothesize that the coefficient of the HIE variable is negative and expect that holding all of the other variables constant, querying the HIE to reduce the number of laboratory tests and radiology examinations performed during the patient’s ED visit.

$$\text{Log}(E(\text{Procedure}_i)) = \beta \text{HIE}_i + C'_i \delta + \epsilon_i \tag{1}$$

In the above specification, procedure is the number of either laboratory tests or radiology examinations.  $C_i$  is a vector of controls for medical history and fixed clinician effects for patient  $i$  as described in the previous section. Note that equation (1) is estimated for laboratory tests and radiology examinations separately. The estimation results of equation (1) are presented in Table 2. The first panel represents the effects of the HIE along with other control variables on reducing the number of laboratory tests. The second panel represents the effects of the same set of variables on the number of radiology examinations. Additional information on the setting, sample, and sensitivity analyses appear in the online appendix.

**RESULTS**

According to the first panel of Table 2, after controlling for provider, patient characteristics, and medical history, the expected log count of laboratory tests decreases by 0.7248 units for patients in the treatment group. This implies that the number of laboratory tests is expected to reduce by 52% in patients whose case included an HIE query ( $\log\left(\frac{\text{HIE}}{\text{noHIE}}\right) = -0.7248 \rightarrow \frac{\text{HIE}}{\text{noHIE}} = 0.48$ ).

The second panel of Table 2 presents the effects of the HIE on the number of radiology examinations created for patients during the ED visit. Ceteris paribus, the expected log count of radiology examinations decreases by 0.4363 units for patients in the treatment group. This implies that the number of radiology examinations is expected to reduce by 36% in patients for whom their care includes an HIE query ( $\log\left(\frac{\text{HIE}}{\text{noHIE}}\right) = -0.4363 \rightarrow \frac{\text{HIE}}{\text{noHIE}} = 0.64$ ).

Note that variables provider 1 to provider 6 capture the fixed effects associated with the 6 different ED providers in the treatment

Table 1: Descriptive Statistics on Patient Characteristics

Variable	Treatment group, n = 698			Control group, n = 1275			H <sub>0</sub> : μ <sub>C</sub> - μ <sub>T</sub> = 0
	Mean (SD)	Min	Max	Mean (SD)	Min	Max	t-value
Age	54.94 (20.44)	6	90	52.33 (21.95)	2	90	-2.64**
Female = 1	0.54 (0.44)	0	1	0.57 (0.49)	0	1	1.01
Prior laboratory tests	11.44 (32.90)	0	344	13.59 (41.58)	0	668	1.26
Prior radiology examinations	1.59 (3.72)	0	34	1.78 (4.13)	0	52	1.03
Prior transcriptions	0.33 (1.18)	0	9	0.41 (1.98)	0	40	1.06
Prior hospitalizations	0.11 (0.46)	0	5	0.13 (0.68)	0	10	0.76
Count of Laboratory tests during the study	14.18 (25.07)	0	213	15.39 (28.56)	0	340	0.97
Count of Radiology exams during the study	1.81 (2.38)	0	22	2.30 (3.12)	0	33	3.96**
At least one Laboratory test during the study	0.62 (0.49)	0	1	0.82 (0.0.39)	0	1	9.23**
At least one Radiology examination during the study	0.63 (0.48)	0	1	0.83 (0.37)	0	1	9.83**

\*\*significant at P < .01; \*significant at P < .05

Table 2. The effect of HIE on reducing the number of procedures performed during ED visit

Parameter	Panel 1 (Laboratory)	Panel 2 (Radiology)
	Estimate (Std. Err.)	Estimate (Std. Err.)
Intercept	1.04 (0.11)**	−0.46 (0.08)**
HIE	−0.72 (0.13)**	−0.44 (0.07)**
Age	0.02 (0.001)**	0.01 (0.001)**
Female = 1	−0.24 (0.07)**	−0.17 (0.04)**
Prior laboratory tests	0.007 (0.002)**	0.0004 (0.0009)
Prior radiology exams	−0.005 (0.01)	0.04 (0.01)**
Prior transcriptions	0.019 (0.03)	0.03 (0.02)
Prior hospitalizations	0.07 (0.12)	−0.06 (0.07)
Provider 1	0.67 (0.09)**	0.68 (0.07)**
Provider 2	0.39 (0.11)**	0.41 (0.09)**
Provider 3	1.09 (0.15)**	0.74 (0.10)**
Provider 4	1.26 (0.16)**	0.78 (0.10)**
Provider 5	0.43 (0.19)*	0.35 (0.14)*
Provider 6	0.98 (0.14)**	0.61 (0.09)**
	Dispersion: 1.8551 (0.06)**	Dispersion: 0.5018 (0.03)**
	AIC: 13 555.69	AIC: 7260.79
	Deviance: 2274.12	Deviance: 2026.72

\*\*Significant at  $P < .01$ ; \*significant at  $P < .05$ .

group. The coefficients of these variables compare them with other providers in the control group.

## DISCUSSION

To the best of our knowledge, this is the first study in which querying the HIE was included in the treatment process of all the patients in a treatment group, while the care of the others in the control group did not include an HIE query. This feature of our experiment design enables us to avoid endogeneity and confounding effects and thus to establish causal links between the HIE queries and outcome measures. According to our analysis, accessing additional clinical data through the HIE in the ED settings can reduce the number of orders for laboratory tests and radiology examinations by, respectively, 52% and 36%.

Findings of this research may not be generalizable to other areas because HEALTHeLINK has very high and longstanding participation rates among ambulatory providers. As such, the information within the HIE system represents a fairly comprehensive and longitudinal record. Since the potential benefits of an HIE is proportionate to the volume of clinical data that can be accessed on it,<sup>1–3</sup> similar effects may not be observed in other HIE settings. Another limitation to the external validity of this study is the use of the medical liaisons. Not all other HIE efforts will have staff dedicated to facilitate provider access to information. The effects in other settings may be further attenuated due to this feature of our research. However, we felt that the additional staff

were best approach to exploring the impact of the additional information available from the HIE and avoiding the low usage rates that limit other studies<sup>4–13</sup> in which HIE usage is completely voluntary.

The salient effects of querying the HIE on reducing the number of test and examination orders further highlights the importance of integrating HIE queries with the routine workflow of ED providers. A hundred percent rate of querying which was implemented in this trial can be achieved by reengineering the workflow processes and implementing automatic querying technologies.

Since we did not have access to initial diagnosis codes or the acutely level of patients, we could not directly control for these measures. To overcome this limitation, the number of previous medical records and hospitalizations are used as a proxy for adjusting the differences in the risk levels among patients. Moreover, ethically we are not able to conduct a completely randomized trial by avoiding the care providers to access HIE for the patients in the control group and can only eliminate those rare instances from the study. Although this introduces some bias in the study, the bias will only lead to underestimation of the HIE effects. See online [appendix](#) for further discussions.

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## COMPETING INTERESTS

The author is a Scientific Adviser to HEALTHeLINK. He does not receive financial compensation from HEALTHeLINK.

## CONTRIBUTORS

The author is solely responsible for this work.

## SUPPLEMENTARY MATERIAL

Supplementary material is available online at <http://jamia.oxfordjournals.org/>.

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# Online Supplement for “An Empirical Analysis of the Financial Benefits of Health Information Exchange in Emergency Departments”

## A. CONCEPTUAL TOPICS

### A.1. Regional Health Information Organizations

*“An epidemic of waste blights the US health care delivery system.”*<sup>1</sup> It accounts for at least 20% of the total health care expenses in America.<sup>2</sup> Among the different approaches to health information exchange (HIE), sharing medical information through regional health information organizations (RHIOs) is the most widely accepted.<sup>3</sup> RHIOs act as neutral organizations which promote and facilitate the exchange of medical information between providers within a geographical region.<sup>4-6</sup> Despite their potential benefits and the support of the federal government, many of the RHIOs are not yet financially sustainable<sup>7,8</sup> and the majority of providers are not actively engaged in any type of HIE.<sup>9</sup> To generate a dependable source of revenue and become financially sustainable, RHIOs have to quantify and measure the value of their services in financial terms. Precise estimation of the economic and medical value of these services would drive medical providers to join RHIOs and actively engage in HIE. This will ensure the financial sustainability of RHIOs, increase the efficiency of health care services, and ultimately benefit patients.

### A.2. Setting: HEALTHeLINK

HEALTHeLINK provides fully operational query based HIE services to over 3300 members in Western New York. All of the major medical data providers in the region have already joined the platform. When a patient provides consent, HEALTHeLINK subscribers will have access to the medical records through either a fully automated system which pushes the medical data into their interoperable electronic medical records (EMR) systems or through a web portal in which they can search for the available medical history

of their patients. The ED in this study has access to the HIE services via this web portal. Before this study, the ED accessed HIE services in less than 5% of the patient visits. The ED is located in an average sized suburban hospital. The most recent source of publically available data on the ED visits in New York states is provided by Department of Health in 2006 and can be accessed here:

<http://www.health.ny.gov/statistics/sparcs/ed/>

According to these statistics, the number of visits to the ED is very close to the median number of ED visits in the region.

### **A.3. Previous Research on HIE**

In the following, we review the most recent studies on the effectiveness of the HIE services and discuss how this research contributes to the literature. Overhage et al.<sup>10</sup> conduct a randomized control trial to analyze the effects of accessing patient information provided by another hospital on the total ED charges as well as repeat orders of specific tests in two settings. While they observe a significant decrease in total charges in ED setting, they do not observe significant reductions in the number of repeated tests. Overhage et al.<sup>10</sup> completed their study in 1996 and their intervention included access to the medical records that were provided by only one hospital. The major difference between this study and that of Overhage et al.<sup>10</sup> is that the shadowed providers in this study had access to the complete medical history of the patients. Rather than being limited to the records created in only one hospital, the medical history of patients at HEALTHeLINK includes all of the records that have been created by all of the major data providers (laboratories, radiology centers and hospitals) in the region. This is a luxury that the advances in technology has provided and enables us to study the effects of reviewing complete medical history rather than partial histories. Assigning dedicated medical liaison to retrieve the medical records is another unique feature of this study that ensures providers have actually seen such records.

Vest<sup>11</sup> studies the association between the HIE access rates and the emergency room visits and inpatient hospitalizations over a period of two and a half years in a group of 6114 patients in Texas. According to his analysis, the HIE access is strongly associated with significant increases in frequency of ED visits and hospitalizations. While this is an unexpected observation, it highlights the role of confounding factors that if unadjusted for, can significantly obscure our understanding of the effects of HIE access. As Vest<sup>11</sup> himself puts it, *“factors potentially indicative of complex cases, or in other words simply sicker people, increased the odds of providers accessing the HIE information”*. In other words, the medical condition of the patient was determining both the chance of HIE access and also the chance of hospitalization or repeat ED visit. In a similar study, Bailey et al.<sup>12</sup> examine the association between the HIE use and the repeat radiology images for patients with back pain. Although in this context, HIE is shown to have a positive impact on reducing the number of images, the confounding factors affect the conclusions of Bailey et al.<sup>12</sup> in similar way that they affect the conclusions of Vest<sup>11</sup>. Our study does not suffer from the effects of such confounding factors since regardless of the patient condition, we have maintained the rate of HIE access to 100% for all of the patients in the treatment group and 0% for all of the patients in the control group. In other words, HIE access is completely exogenous in our analysis and thus the observed association between the HIE access and the outcomes can be attributed to pure effects of HIE.

Hansagi et al.<sup>13</sup> examine if having access to medical histories of frequent ED users would decrease their subsequent visits to ED. Although in 82% of the cases ED providers deemed such information useful, the authors do not observe any significant differences in the number of ED visits and other utilization measures. Similarly, Proeschold-Bell et al.<sup>14</sup> conduct a randomized trial to examine the association between information exchange and patient health outcomes across a group of human immunodeficiency virus (HIV) care providers. Their treatment group includes the patients whom their information was exchanged with case managers and care providers. Similar to the study of Hansagi et al.<sup>13</sup>, despite the fact that *“most providers indicated perceived value in the set of information exchanged”*, Proeschold-Bell

et al.<sup>14</sup> did not observe significant differences in health outcomes between the control and intervention groups. These seemingly contradictory findings can be attributed to the fact that authors did not study the effects of information exchange at individual patient level and rather compared the averages of the outcome measures between the control and intervention groups. Unless the HIE effect is studied at patient's level, the effects of individual level characteristics cannot be parsed out from the pure effects of information exchange. In our study, the unit of analysis is the patient. This enables us to control for patient specific factors as well as provider fixed effects. More importantly, the medical liaisons in this study ensured that all of the shadowed providers had sufficiently reviewed the medical history of the patients in the treatment group. Although the medical providers in the studies of Hansagi et al.<sup>13</sup>, Proeschold-Bell et al.<sup>14</sup> and Ross et al.<sup>15</sup> had access to patient histories, one cannot be sure that such information was adequately reviewed and actually used to make medical decisions; this question also remains to be answered in some of the studies that report positive outcomes from HIE access. For example, Mäenpää et al.<sup>16</sup> report that the number of radiology examinations decreases after HIE adoption in Finland, Hebel et al.<sup>17</sup> report a significant decrease in the number of laboratory tests in a large population of patients in two academic hospitals in the US, and Wilcox et al.<sup>18</sup> report that improved technical quality of an HIE systems is associated with a significant drop in hospitalizations after ED visit. However, a causal link between HIE adoption and utilization levels cannot be established in neither of the mentioned studies unless one can rule out all of the confounding factors and ensure that the HIE adoption necessarily led to HIE usage.

Observational studies that use propensity score matching to create a comparable control group of patients are amongst the most recent and successful approaches to bridge the above mentioned empirical limitations. The research by Tzeel et al.<sup>19</sup>, Vest et al.<sup>20</sup> and Frisse et al.<sup>21</sup> are examples of such studies. The conclusions of these researchers have high degree of external validity. Our research adds to the literature by providing conclusions with very high degree of internal validity.

#### A.4. Characteristics of This Research

The design of this study differentiates it from previous research. This study is focused on only one ED over a short period of time, and thus it does not suffer from the possible *confounding effects* of unobserved factors. Confounding factors refer to those that may affect both the level of HIE use and care outcomes, yet are commonly unobserved and are not accounted for. Quality of medical technologies, geographical regions, managerial policies, and technology savviness of physicians are examples of such factors. For instance, ED settings in affluent areas may have more financial resources to allocate to HIE efforts and thus will have a higher level of HIE use. At the same time, the patients who visit these ED settings may be more compliant with the advice of ED physicians and thus experience better care outcomes. On the other hand, the EDs which are located in less affluent areas may also have fewer resources to allocate to HIE and as a result have a lower level of HIE usage. The patients who visit these EDs may also have lower medical compliance levels and thus experience worse care outcomes. By regressing the care outcomes on the level of HIE use, one would overestimate the effects of HIE and attribute the effects of unobserved patient characteristics to the HIE usage. Focusing on only one ED setting enables us to establish a causal link between the observed differences in the outcome measures and the HIE use. That is, since confounding factors do not vary, the observed outcomes can be only attributed to the HIE use which varies between control and treatment group.

Moreover, in this study, the medical records were retrieved for all of the patients in the treatment group. This feature ensures that the acuity level, complexity of medical condition, physicians' attitudes toward information technology, or any other factor that may affect the physicians' decision to access HIE is eliminated and thus the results of the analysis does not suffer from *endogeneity of HIE use*. The endogeneity of HIE use stems from the fact that it is not randomly assigned and instead is decided by physicians based on a set of patient- and physician-specific factors. For example, technologically savvy

physicians are more likely to access HIE. These physicians may systematically practice medicine differently from others and thus the differences in the care outcomes that their patients experience may not be necessarily attributed the HIE use. In the seminal studies of Vest et al.<sup>20</sup> and Frisse et al.<sup>21</sup> which are the most similar ones to this research, HIE was used in respectively 5.79% and 6.8% of ED encounters. Although the authors appropriately use propensity score matching techniques to adjust for the endogeneity of HIE use, their conclusions may still be affected by the inherent and inevitable limitation of these techniques. Also, the very low level of HIE use may be a partial reason for which no statistically significant difference in the number of laboratory tests were observed in those studies. Because in this study HIE was accessed for all of the patients in the treatment group and the medical information was provided to the shadowed clinicians even if they had not requested it, the HIE variable is no longer endogenous in this analysis.

The differences in the care outcome may also rise from the differences in how physicians practice medicine. While every medical provider provides the best possible treatment to their patients, they may have different levels of medical skills and expertise which will most likely affect the care outcomes. These factors are unobserved and measuring them is very difficult. We control for these variations by comparing each of the six providers in the shadowed group with those who were not shadowed.

Since almost all of the major data providers in the Western New York region provide at least one type of clinical data to HEALTHeLINK, it is very unlikely to have a patient without any kind of medical information available, unless in one of the following conditions:

- In the consent form, the patient has specifically refused to share his medical records with the providers on the HIE.
- The patient has relocated to the region from another region, state or county and thus his/her medical records have not been uploaded on HEALTHeLINK.

- The patient has never been to any of the medical providers who push data to HEALTHeLINK.

The first condition is the most common reason for which the queries are not successful. There were 39 patients who had not provided consent and thus are excluded from the study. Not every piece of medical information can be deemed relevant to the patient's current situation in the ED. However, we do not have this piece of information since we had not initially collected the information about the physicians' perceptions about the relevance of such information to the condition of the patient. This is a limitation of this study which should be addressed in future research.

## **B. METHODOLOGICAL & EMPIRICAL TOPICS**

### **B.1. Classification Procedure of Patients**

The liaisons were instructed to “wrap-up” all the patients they shadowed and provide the physicians with all of the relevant information from HIE although the patients may have been in the ED when the shift ended. This is due to the fact that the ED physicians would remain in the ED to stabilize the patients, order any necessary tests and exams and ensure the smooth transition of care to the medical teams who take charge of the ED after them. We focus on the first physician who started the medical treatment of a specific patient and check if they were shadowed or not. If a patient's medical treatment has been initiated by a shadowed physician and then continued by a non-shadowed physician in the next shift, we consider him/her as a member of treatment group, and in our analysis only include the laboratory tests and radiology exams that were ordered for that patient by a shadowed physician. If a patient was admitted to the ED before the shadowed physicians started their shift (and the ED physicians had not looked up his/her records on HIE before), we consider him/her as a member of the control group since the shadowed physicians were only provided with HIE information for the new patients.

Figure A1 summarizes our classification approach. Patient 1 has been admitted and discharged during a shadowed shift and thus is in treatment group. Patient 2 has spent the initial time of his care process at

the shadowed shift. For that period of time, he is considered as a member of treatment group. The laboratory tests and radiology exams of patient 2 are only counted if they were ordered during the shadowed shift by a shadowed physician. Medical liaisons did not query the medical records of patient 3 since he was already admitted to the ED before the shadowed shift started and thus is considered as a member of control group.

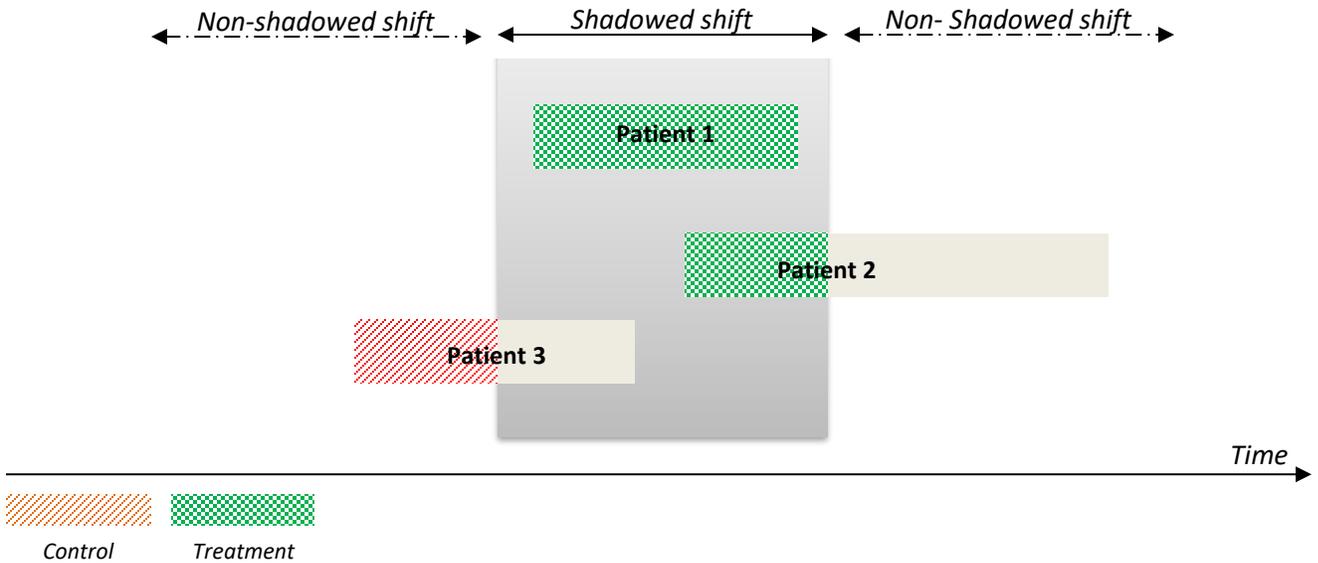


Figure A1: The procedure of classifying patients into treatment and control groups

We removed the observations in which a provider had accessed the HIE system to look up the medical records of a patient in the control group. The patients in the control group for whom the HIE was accessed tend to have higher acuity levels which warrants the ED providers to actively look for further information on the HIE. Due to their critical medical conditions, these patients also tend to need more laboratory tests and radiology examinations. As discussed above, in order to be able to capture the pure effects of HIE, we had to remove these patients from the analysis. This will introduce some bias because a very small percentage of the sicker patients are removed from the control group and thus the patients in the treatment group will be sicker than those in the control group. This bias is inevitable, since the HIE access, as a critical part of medical care, cannot be revoked for those patients in the control group, however, it

only leads to underestimation of the HIE effects. Had it been ethically possible to conduct a purely randomized control trial and restrict the HIE access for all of the patients in the control group and thus keep the sicker patients in the analysis pool, then the effects of HIE access would have been more salient since the number of medical procedures performed on the sicker patients in the control group would have been even more than what we observe in the limited pool of healthier patients in the current control group.

The exclusion of such patients is also justified based on empirical estimation of the model. We excluded these patients to ensure that we are correctly considering the effects of provider characteristics and severity of the medical condition into account. In our estimation model, we have six binary variables which represent the fixed effects of providers in the shadowed group. The estimated coefficients of these variables capture the differences in the number of test orders that can be attributed to the unobserved characteristics of each shadowed provider. If we had kept the patients whom their records were accessed in the control group, then we should have also included a new dummy variable to capture the individual level characteristics of the provider who treated them in the control group. This will introduce a large number of dummy variables into the model and will make the estimation results increasingly difficult to interpret. As a robustness check, we kept such patients in the control group and did the analysis again (by introducing more dummy variables). The estimates of the HIE coefficient remain very similar to the main results.

## **B.2. Descriptive statistics on providers**

Descriptive statistics in both treatment and control groups are presented in table A1. We used the HIE log files over the year prior to the start of the study to compare the utilization behavior of clinicians in the two groups. The last rows of table A1 respectively pertain to the number of laboratory tests and radiology

examinations that clinicians have ordered per each patient over the past year. There is no statistically significant difference between the observed characteristics of the providers in the two groups. Although with varying degrees of enthusiasm, all of the providers who were asked to participate in this study, agreed to do so. The treated clinicians were selected based on a convenience sampling method. That is, they are the ones who were present at the very first shifts were the liaisons started their job and were followed afterwards. To protect patients' privacy and ensure that the data cannot be re-identified, HEALTHeLINK is not identifying the shift in which an ED encounter occurred. Instead, HEALTHeLINK provided us with the aggregated data on the mix of the shifts. If we knew the exact shift of each ED encounter, we could ideally control for that in our models, but the lack of available data presents a limitation in our analysis. The percentage of the morning, afternoon and evening shifts in the treatment group is respectively 43%, 47% and 10%. The percentage of the morning, afternoon and evening shifts in the control group is respectively 28%, 26% and 45%.

Variable	Treatment group N=6				Control group N=12				$H_0: \mu_C - \mu_T = 0$
	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max	t-value
Experience (in years)	14	8.67	5	31	18.9	8.87	8	34	1.12
Female=1	0.33	0.47	0	1	0.17	0.37	0	1	-0.79
# of orders for laboratory tests per patient over the past year	15.21	1.41	0	254	16.05	.98	0	198	1.48
# of orders for radiology exams per patient over the past year	2.15	0.51	0	21	2.44	0.87	0	35	0.89

*Table A1: Descriptive statistics on Provider Characteristics*

### B.3. Alternative Analysis Method

In this alternative analysis, the dependent variable is dichotomous and is equal to one if at least one laboratory test (and radiology examination) was performed during the ED visit. We apply a multivariate logistic regression to respectively estimate the effects of accessing HIE on the *likelihood* of creating *at least one* laboratory test and radiology examination. We hypothesize that the coefficient of *HIE* variable

is negative and expect that holding all of the other factors constant, accessing HIE would reduce the likelihood of creating at least one laboratory test (and radiology examination) during the patient's ED visit.

$$\log\left(\frac{p_i}{1-p_i}\right) = \beta HIE_i + \mathbf{C}'_i \boldsymbol{\delta} \quad (1)$$

In the above specification,  $p_i$  is the probability of performing at least one procedure (laboratory test, radiology examination) for a patient during the ED visit and  $\mathbf{C}_i$  is a vector of controls for medical history and fixed clinician effects for patient  $i$  as described in the previous section. Note that equation (1) is estimated for laboratory tests and radiology examinations separately. The estimation results of equation (1) are presented in table A2. The first panel represents the effects of  $HIE$  along with other control variables on reducing the likelihood of creating at least one laboratory test. The second panel represents the effects of the same set of variables on creating at least one radiology examination.

To estimate the savings associated with HIE use in the ED settings, we follow the method proposed by Vest et al.<sup>20</sup> and Frisse et al.<sup>21</sup> In this method, the marginal probability of performing at least one laboratory test on the patients in the treatment group is estimated under two scenarios: We first assign the HIE variable a value of zero and estimate the marginal probability of performing at least one laboratory test based on the estimated coefficients of equation (1) (presented in first panel of table A2 below). Using the same set of coefficients and variables, we then estimate the marginal probability of performing at least one laboratory test for each patient by assigning the HIE variable a value of 1. The difference between the estimated probabilities in these two scenarios would capture the effects of HIE on reducing the probability of performing at least one laboratory test. We calculate the average of the estimated reductions in the marginal probability for all the patients in the treatment group and multiply it by the total number of patients in this group. We then multiply this value by the average cost of a typical laboratory test in Western New York area to calculate the overall savings associated with the reduced probability of performing laboratory tests during the period of the study. Following the similar method,

we use the coefficients reported in the second panel of table A2 to estimate the overall savings associated with the reduced probability of performing radiology examinations during the period of the study. The limitation of this method is that it cannot take the *number* of procedures into account. For example if three laboratory tests were created for a patient whose treatment included HIE access and five laboratory tests were create for a similar patient whose treatment did not include HIE access, then the this method underestimates the effects of HIE despite the fact that in this hypothetical scenario HIE access has reduced the number of laboratory tests by two units. This is due to the fact that this method uses a logistic specification and its dependent variable (*whether or not at least one laboratory tests was created*) is equal to one in both cases.

The method reported in the main text uses the actual number of procedures rather than the probability of creating at least one procedure and thus does not suffer from the limitation of the method reported here in the online appendix. To estimate the savings associated with the HIE use based on the estimation results of the method reported in the main paper, we estimate the number of laboratory tests for the patients in the treatment group under two scenarios. We use the coefficients reported in the first panel of table 2 in the main text along with the value of control variables for each patient and assign a value of 1 to HIE variable to estimate the expected number of laboratory tests when HIE is accessed. In the second scenario, we assign a value of 0 to HIE variable and estimate the counterfactual number of laboratory tests had HIE not been accessed. The difference between these two values over all of the patients in the treatment group will be the estimated reduction in the number of laboratory tests which is associated with the HIE use. We then multiply this value by the average cost of a typical laboratory test in Western New York to calculate the overall savings associated with the use of HIE during the time of the study. Similarly, we estimate the savings associated with the reductions in the number of radiology examinations based on the coefficients reported in second panel of table 2.

The first panel of table A2 presents the results of analyzing the effects of HIE on the likelihood of performing at least one laboratory test on the patients during the ED visit. The second panel of table A2 presents the effects of the same factors on the likelihood of creating at least one radiology examination. According to the results, accessing HIE is associated with 2.0750 units of decrease in the log odds of performing at least one laboratory test. This implies that if all the other factors are held constant, accessing HIE will be associated with 87.5% lower odds of performing at least one laboratory test. As indicated in the second panel of table A2, accessing HIE also has a significant effect on reducing the odds of creating at least one radiology examination (log odds=-1.7183). That is, controlling for all the other factors, accessing HIE is associated with 80% lower odds of ordering at least one radiology examination.

The significant fixed effects are interpreted as the effects of the unobserved physician level characteristics that affect the number of lab and radiology orders. By including these effects in the model we acknowledge that there are some characteristics that we are not able to measure yet they will affect the number of test orders. The medical expertise of physicians or their beliefs in the necessity of tests are examples of such characteristics. The estimated coefficient of Provider 1 in panel 1 of table A2 is equal to -0.45. This means that the log count of the lab tests that this specific physician orders for a patient is 0.45 units lower than the average of providers in the control group.

Parameter	Panel 1 (Laboratory)		Panel 2 (Radiology)	
	Estimate	(Std. Err.)	Estimate	(Std. Err.)
Intercept	1.27	(0.18)**	1.45	(0.18)**
<b>HIE</b>	<b>-2.07</b>	<b>(0.20)**</b>	<b>-1.71</b>	<b>(0.19)**</b>
Age	0.01	(0.002)**	0.01	(0.002)**
Female=1	-0.17	(0.12)	-0.50	(0.12)**
Prior laboratory tests	0.02	(0.007)**	-0.004	(0.003)
Prior radiology exams	0.01	(0.03)	0.07	(0.03)*
Prior transcriptions	-0.01	(0.15)	0.08	(0.09)
Prior hospitalizations	0.13	(0.47)	-0.27	(0.23)

	Panel 1 (Laboratory)	Panel 2 (Radiology)
Provider 1	-0.45 (0.15)**	-0.07 (0.16)
Provider 2	-0.42 (0.19)*	-0.16 (0.20)
Provider 3	0.73 (0.18)**	0.48 (0.17)**
Provider 4	1.45 (0.20)**	0.78 (0.19)**
Provider 5	-0.83 (0.28)**	-0.33 (0.32)
Provider 6	0.64 (0.16)**	0.53 (0.16)**
	AIC: 1900.48	AIC: 1860.64
	-2LL: 1870.48	-2LL: 1830.64

\*\*: significant at p<0.01; \*: significant at p<0.05

*Table A2: The effect of HIE on performing the odds of ordering at least one procedure*

#### **B.4. Estimated Savings**

Each stakeholder in any patient care episode is impacted differently by the use of HIE. The total impact on the community therefore includes direct and indirect events. Direct would include the cost of procedure regents, technician time to run the procedures and any professional fees to interpret the results. Indirect events include decreases turnaround time of the patient in the ED, decreased radiation exposure to the population over time, elimination of the costs incurred by working up false positive results from the unnecessary procedures and increased diagnostic efficiency of the physicians in triage of patients now with an accurate and complete medical history rather than one that relies on patient or patient’s family member memory of past medical events. To serve as a benchmark figure, we assigned dollar values of \$50 and \$300 for laboratory tests and radiology examinations respectively. These figures are based on local interviews and reflect the overall impact of HIE in the community of Western New York. Since the costs of healthcare services vary significantly in different geographical regions, the corresponding impact of HIE on the communities will also vary accordingly.

Following the method presented here in the online appendix, the use of HIE is estimated to reduce the total number of laboratory tests by 185 units. The savings associated with the use of HIE during the time of study will be \$9,250 in reduced laboratory tests. Similarly, it is estimated that accessing HIE reduced the total number of radiology examinations by 164 units. The savings associated with the use of HIE during

the time of study will be \$49,200. Overall, HIE is estimated to have saved \$58,450 by reducing the number of laboratory tests and radiology examinations. Averaging the total savings on the number of patients in the treatment group leads to an estimated savings of \$83 per patient visit to the ED according to the most conservative estimation method.

### **B.5. Sensitivity Analysis**

The medical liaisons attended a training session in which they were briefed about the project, how to access HIE database and how to provide the shadowed clinicians with the HIE information without interrupting the workflow at the ED. Each medical liaison was paid an hourly wage of 14 dollars. They were paid a total of \$6,300 over the two months of the project. A typical medical assistant can be easily trained to perform the tasks of the medical liaisons of this project with equal quality. The number of assistants required for providing data depends on the workflow and how different medical team members collaborate with each other as a team. In this project, one medical liaison was assigned per shift.

While in practical settings it is difficult and unnecessary to use HIE for 100% of the patients, in our experiment we had to keep the HIE usage at 100% in the treatment group and 0% in control group in order to make sure that our “intervention” is completely exogenous and independent from the cases in either of the treatment and control groups. This feature of our experiment design allows us to establish a causal link between the HIE use and patient outcomes and ensure that our result does not suffer from the potential confounding factors that affect the physicians decision to use HIE.

The following Pareto charts show the laboratory tests and radiology examinations that contributed to at least 70% of the total reductions in test and exam orders.

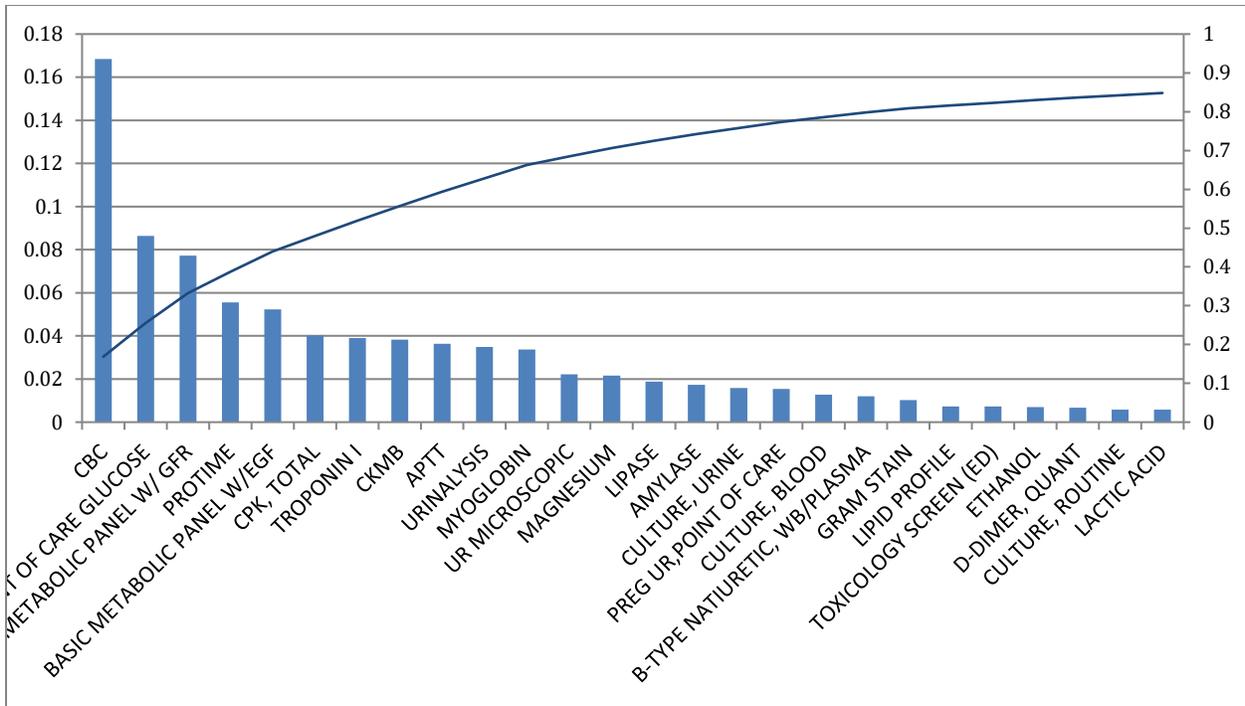


Figure A2: The Pareto charts of the laboratory tests

Note: The chart reflects the share of each test in the total reduction in number of orders for laboratory tests. The percentage of reduction by each test is shown on left vertical axis. The cumulative percentage of reduction is shown on right vertical axis.

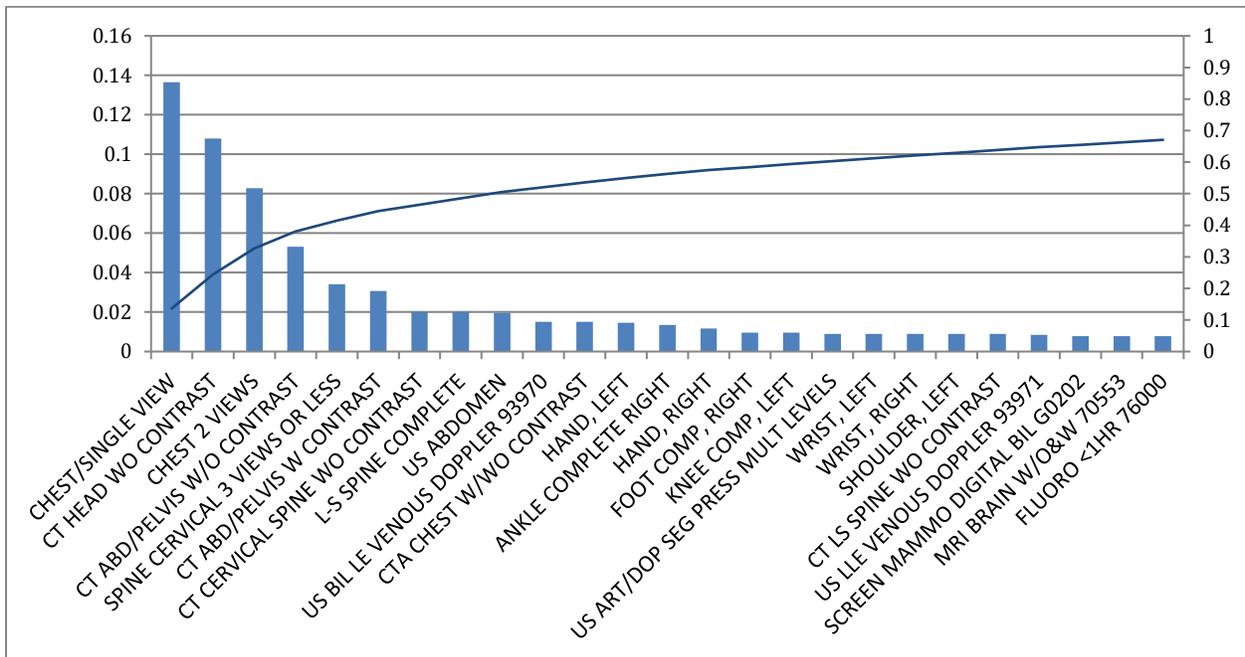


Figure A3: The Pareto chart of the radiology examinations

Note: The charts reflect the share of each exam in the total reduction in number of orders for radiology examinations. The percentage of reduction by each exam is shown on left vertical axis. The cumulative percentage of reduction is shown on right vertical axis.

Prior laboratory tests (radiology examinations) may be the most relevant type of information to help physicians avoid re-ordering redundant laboratory tests (radiology examinations); however they are not the only available source of information. Prior hospitalization and medication histories of the patients are examples of other sources of useful information that may affect the utilization of laboratory tests (radiology examinations) at the ED. Since HEALTHeLINK has almost all of the major data providers on board, the volume of available information for each patient is significantly high. This special feature of HEALTHeLINK allows us to assume that a minimum level of relevant information was available on HIE for the majority of the patients in the study. If we take out the variable representing laboratory tests (radiology examinations) from the laboratory tests (radiology examinations) model, run the regression models again, the estimated effects of the HIE coefficient remain very close to the original estimates presented in the main paper.

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