Optimizing financial effects of HIE: a multi-party linear programming approach

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ABSTRACT

Objective To describe an analytical framework for quantifying the societal savings and financial consequences of a health information exchange (HIE), and to demonstrate its use in designing pricing policies for sustainable HIEs.

Materials and methods We developed a linear programming model to (1) quantify the financial worth of HIE information to each of its participating institutions and (2) evaluate three HIE pricing policies: fixed-rate annual, charge per visit, and charge per look-up. We considered three desired outcomes of HIE-related emergency care (modeled as parameters): preventing unrequired hospitalizations, reducing duplicate tests, and avoiding emergency department (ED) visits. We applied this framework to 4639 ED encounters over a 12-month period in three large EDs in Milwaukee, Wisconsin, using Medicare/Medicaid claims data, public reports of hospital admissions, published payer mix data, and use data from a not-for-profit regional HIE.

Results For this HIE, data accesses produced net financial gains for all providers and payers. Gains, due to HIE, were more significant for providers with more health maintenance organizations patients. Reducing unrequired hospitalizations and avoiding repeat ED visits were responsible for more than 70% of the savings. The results showed that fixed annual subscriptions can sustain this HIE, while ensuring financial gains to all participants. Sensitivity analysis revealed that the results were robust to uncertainties in modeling parameters.

Discussion Our specific HIE pricing recommendations depend on the unique characteristics of this study population. However, our main contribution is the modeling approach, which is broadly applicable to other populations.

INTRODUCTION

Health information exchanges (HIEs) provide an potentially efficient mechanism for sharing data across disparate institutions.[1 2] Accurate financial models are essential for designing sustainable HIEs and for developing pricing, charging, and subsidy strategies that yield a financial benefit to all participants. To date, efforts to evaluate the financial consequences of HIEs have focused on the actual[3] or estimated[4] societal value that HIEs create by providing access to complete, relevant patient data, or by documenting changes in mean per-patient care charge in emergency rooms.[5 6] Healthcare systems, payers, and HIEs themselves require more explicit guidance regarding pricing, charging, and subscription policies that ensure financial viability and sustainability.[7] Simplified approaches based on calculating the return-on-investment for each institution ignore market uncertainties and sometimes lead to choices that conflict with the institution's best interests.[8]

Developing a financial model for HIE requires making several choices. First, the modeling approach must account for the uncoordinated actions of multiple agents: providers, payers, and the HIE organization itself. These agents may have incentives that conflict with optimal system-wide performance. Models must also be sufficiently sensitive to detect the financial consequences of strategies that reduce costs for the overall system, but not for some individual agents. Second, there must be enough trustable data to instantiate the model. Third, the key objectives, constraints, and decisions for each agent must be formulated in precise terms. In this work, we use linear programming (LP) to construct, solve, and interpret the results from models of this type.

In this paper, we describe the LP framework, populating it with data from various sources, and validating its robustness against various modeling assumptions and parameters. We demonstrate how this framework can be used to (1) guide pricing and subscription strategies and (2) study the financial consequences of one agent's actions on all other agents in the HIE system (online appendix C). The goal of this work is to develop a broadly applicable framework that assists decision making involving the use and implementation of HIE systems in various institutions.

BACKGROUND

Dixon *et al*[9] described a framework to evaluate the costs, effort, and value between an HIE and all participating institutions. This paper builds on the HIE assessment framework advanced by Dixon *et al*[9] and explicates the *value-to-all-participating-agents* component of that framework. By attending to the considerations of each HIE-participating agent, we address the problem of multiple perspectives raised by Dixon's respondents. Because HIEs are alliances of institutions, we have developed a financial model that accounts for the effects of the behavior of each institutional agent on all other agents in the system. We have drawn from Overhage *et al*[6] to identify three desired effects of HIE: avoiding unnecessary emergency department (ED) visits, reducing duplicate tests, and reducing unrequired ED-related hospitalizations. These effects appear as *parameters* in the model. We have also incorporated an understanding of the care production system by exploring a locally important effect of the HIE: avoidance of ED visits. ED visits can be avoided if a case manager consults an HIE during the patient's index ED visit and initiates an appropriate plan for follow-up care.

This research was motivated by an evaluation sponsored by the Centers for Medicare & Medicaid Services (CMS), and was the target of a multi-year, multidisciplinary project on the application of operations research to HIEs. The Indiana Health Information Exchange provided early insights into the multi-actor challenges of HIE participation.[10] Subsequent research with the Wisconsin Health Information Exchange (WHIE) provided the HIE data for this report. WHIE is a not-for-profit corporation that houses a community-wide data repository built within the Microsoft Amalga platform. Although WHIE currently engages 22 institutions across five different health systems, this paper focuses only on the original three healthcare providers participating with WHIE. This evaluation project was reviewed and approved by the UW Health Sciences Institutional Review Board.[11]

MEASUREMENTS AND METHODS

Linear programming

LP is a mathematical modeling framework for identifying the optimal decisions that an agent should make in order to maximize an objective, given a set of requirements. The decision options open to agents are *decision variables* ($x_1, x_2 \ldots x_N$), the requirements are termed *constraints*, and the quality of the outcome is measured using an *objective* function. In LP, the objective function ($c_1x_1 + c_2x_2 \ldots c_Nx_N$) and constraints ($a_{j1}x_1 + a_{j2}x_2 \ldots a_{jN}X_N \leq b_j \forall j = 1 \ldots M$) can be expressed using linear functions of the decision variables. LPs contain *parameters* (a_{ij}, b_j, c_i), whose values are fixed in each instantiation of the model, but may change if the model is adapted to different data sets and different situations. Efficient software is available for solving LP models with millions of decision variables. Mathematically, an LP can be written as:

$$\max c_1x_1 + c_2x_2 \ldots + c_Nx_N$$
$$\text{subject to } a_{1j}x_1 + a_{2j}x_2 \ldots a_{Nj}x_N \leq b_j \ \forall j = 1 \ldots M$$
$$x_i \geq 0 \ \forall i = 1 \ldots N$$

Model outline

In many LP models, a natural choice for an objective is to maximize profit, but this is not appropriate for this study since WHIE is a not-for-profit organization. Hence, we defined the objective to be the total financial benefit, due to HIE, across all participating agents. The main *decision variables* were the charging and subscription rates for providers and payers. Two basic *constraints* specified for this HIE model were financial sustainability (the HIE does not lose money) and a minimum financial benefit of 0.5% for each agent in the system. (The minimum financial benefit parameter, that is, 0.5%, can be varied to investigate different settings.) Other key *parameters* arose from the anticipated impacts of the HIE. We focused on three particular impacts:

- Reduction of unrequired ED-related hospitalizations (denoted as 'UH'), which we defined as those that occur because there is insufficient information available in the ED to make a diagnosis and disposition
- Reduction of duplicated test and imaging studies (denoted as 'Dup') performed inside the ED
- Avoidance of repeat ED visits (denoted as 'AED') via case management. Note that repeat ED visits are ED visits that reoccur, for the same diagnosis, within 15 days of a previous ED visit.

We identified three types of agents participating in the HIE: (1) healthcare providers (hospitals); (2) payers (commercial insurance companies, health maintenance organizations (HMO), and governmental agencies); and (3) the HIE organization. Figure 1 illustrates the flow of data and money among these agents. Data flows are indicated by dotted lines and cash flows by solid lines. The shading of the payer nodes indicates the source of payment: private insurance providers or government-funded (all government funds are denoted as 'government'). Data exchange constituted patient care events, test results, and prescribed medication lists. Cash flow included subscription fees to WHIE and payment for services from various payers.

Payers were divided into three major categories: commercial insurance companies, HMOs, and government. Our model allowed for a hybrid payer (eg, government-sponsored HMO). Self-payers were omitted, as there were relatively few payers in this category.

We made the following assumptions while modeling the payer–provider financial contracts (more details about our mathematical model are available in online appendix B):

- Commercial insurance companies reimburse healthcare providers for all their customers on a per-procedure basis.
- HMOs follow a capitated fee structure: payments from the HMO to the ED are fixed amounts per admission over a defined scope of services for a defined population set, regardless of actual services provided.
- A certain percentage of Medicare patients are subcontracted by the government to the HMO, while the remainder are handled directly through government payments to providers on a per-procedure basis.

Designing subscription schemes for sustainable HIEs

Designing sustainable business models for HIE is a challenging task. Although societal benefits, for HIE, have been demonstrated, sustainability requires careful design of the subscription mechanism. An ideal subscription policy provides a predictable cash flow to the HIE, maintains equity across participating agents, and avoids disincentives for providers to use the HIE.

For payers, we considered only fixed-annual-rate subscriptions to the HIE because they have no control over how the providers use the HIE system. For providers, we considered three charging schemes:

- Fixed annual fee or subsidy: a fixed annual cash transfer is established between the HIE and the provider that is bilateral and independent of the agent's frequency of use of the HIE. This scheme provides a fixed revenue stream to an HIE while providing an incentive to providers to use the system frequently.
- Per ED visit: HIE charges (or subsidizes) providers per ED visit. This scheme also provides a fixed revenue stream to an HIE and does not provide a disincentive for the use of the system.
- Per look-up: HIE charges (or subsidizes) providers each time they seek medical information from the HIE server. This scheme gives providers the control and flexibility of budgeting their HIE expenses. However, it can dissuade providers from using the HIE, which can subsequently reduce the revenue stream to an HIE.

While the above list is not exhaustive, our framework can be extended to evaluate other possible subscription schemes.

DATA

Study population

We instantiated our model with a data set consisting of patients with a high volume of service usage and complex care needs. We created a complete data set of patients, from three EDs, diagnosed with chronic diagnoses—specifically, asthma, chronic lung diseases, and diabetes. Providers accrued an aggregate profit of

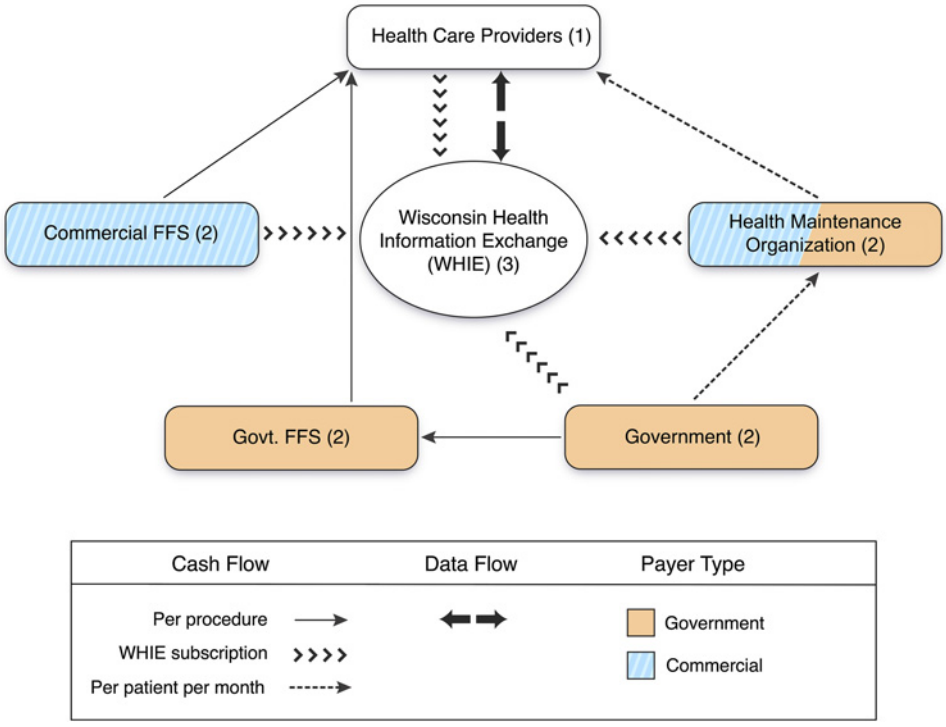

Figure 1 Cash and data flows involving the Health information exchange. FFS, fee-for-service.

4%–14% for the care of the patients in our study group. Table 1 summarizes patient statistics along with their association with different payer types (see online appendix A for additional details).

Table 1 Visit summary statistics grouped by agent type

	Statistics			
Agents	**Hospital ID**	**ED visits (repeat ED visits)***	**Procedures per visit***	**Average amount claimed†**
Provider (1)	Medicaid/Medicare (asthma/COPD/diabetes)			
	1	1600 (134)	1.96	$2044
	2	981 (93)	2.09	$2323
	3	1066 (84)	1.73	$1815
	Commercial insurance (asthma/COPD/diabetes)			
	1	284 (24)	1.93	$2996
	2	494 (47)	1.94	$2902
	3	214 (17)	1.92	$2936

	Statistics				
			Average annual premiums¶		
Agents		**ED visits**	**Commercial**	**Government**	**Total premium**
Payer (2)	All hospitals (asthma/COPD/diabetes)				
	HMO	3240**	$5036	$2727	$5.69M
	Government FFS	754*	NA		NA
	Commercial FFS	634‡	$6043		$7.89M
WHIE (3)	Operating cost (22 hospitals)††		Operating cost (3 hospitals)‡		
	$500K		$150K		

*State of Wisconsin Medicare/Medicaid claims: exact visit and procedure counts.
†State of Wisconsin Medicare/Medicaid claims: exact charges from the State of Wisconsin Medicaid claims.
‡Calculated data: average amount claimed by the providers from payers (refer to online appendix).
¶Reports filed to State of Wisconsin Commissioner (refer to appendix).
**Exact for Government HMO and estimated for commercial HMO (refer to appendix).
††Personal communication (CEO, WHIE).
COPD, chronic obstructive pulmonary disease; ED, emergency department; FFS, fee-for-service; HMO, health maintenance organizations; WHIE, Wisconsin Health Information Exchange.

The visit statistics for the study population, summarized in table 1, encompassed 3.7% of all ED visits for these three providers during the 1-year period in question. These data suffice to build a model because: (1) patients with these three conditions are high consumers of clinical services and, therefore, are most likely to benefit from HIEs; (2) the experience data for these diagnoses are extensive and detailed enough to warrant confidence in the model; and (3) the financial impacts detected here represent the minimum likely impact for an institution and could be extended to full system operation.

Sources

To build our model, we acquired several types of data, including patient arrivals to hospitals, care practices such as test ordering and admissions procedures, costs and payments for testing and imaging services, and use statistics for the HIE. We consulted published data sets, extracts from claims data, and publicly available hospital data. For each hospital, we examined ED arrivals and any subsequent hospitalizations for all patients seen in fiscal year 2008–2009. We also acquired other indicators of care processes, including use of a case manager by a patient, number of times a medical procedure occurred, and actual or computed payer costs for each case. Cost data were obtained from an extract of State of Wisconsin Medicare/Medicaid claims and from public reports of premiums from insurance companies. The analyses used to create the data elements and determine charges for care events are detailed in online appendix A.

HIE operating cost

We obtained an estimate of HIE operating costs from the director of the WHIE (K Pemble, personal communication, October 15, 2011). The amount reflects a proportion of the operating costs required to support an exchange involving three providers. The goal of this paper is not to demonstrate the sustainability of WHIE from a limited set of patients and hospitals, but rather to demonstrate how pricing policy and subscription plans can affect the participation and use of HIE.

Modeling parameters

Our model requires estimates of the HIE-associated reductions in the three aspects of ED operations (ie, unrequired ED-related hospitalizations, duplicative tests and imaging studies performed inside the ED, and avoidable repeat ED visits) due to the presence of an HIE. From these estimates, or *parameters*, we define the *base case*—a 'benchmark' choice used as a starting point for our calculations of savings due to HIE. LP sensitivity analysis helps determine how variations from the base case can be attributed to variations in the parameters of the model. In particular, sensitivity analysis determines precisely how each agent is affected if more or less conservative estimates of HIE-associated savings are used. Table 2 lists the base-case parameters as well as the variations used to evaluate their sensitivity.

Unrequired ED-related hospitalizations

Yasnoff[12] posited that 14% of ED-related hospitalizations occur because information about a patient is not available; local experts argued that this proportion was closer to 50%, while Overhage *et al*[6] were unable to demonstrate any effect of HIE on preventing unrequired hospitalizations. Our base-case assumption revealed that the HIE reduces by 10% the 46 ED-related hospitalizations in our study population. We varied this parameter in five steps from 6% to 14%, symmetrically around the initial estimate.

Duplicative tests and imaging

Estimates[13] from Indiana suggested 13% reductions in diagnostic tests on selected outpatients. These estimates were used[14] to study the effect of HIE-associated ED-related savings due to duplicative tests and imaging. Yasnoff[12] associated HIE use with a 20% reduction in duplicative ED-related medical work. Frisse *et al*[3] demonstrated that, in some settings, there was a slight increase in medical tests when access to HIE information was available. They also indicated that HIE use was more frequent on 'repeat ED visits.'[15] Based on these studies, our base-case assumption was for the HIE to reduce by 20% the 773 medical procedures occurring only during repeat ED visits. We varied this parameter in five steps between 10% and 30%.

Avoidable repeat ED visits

Analysts at the Boston Consulting Group estimated, with secondary data,[16] that 13% of repeat ED visits were potentially avoidable. Goldfield *et al*[17] estimated this figure to be as high as 20% for some patient groups. In the base case, we assumed that 15% of the 399 repeat ED visits could have been avoided with HIE information. We varied this parameter in five steps between 10% and 30%.

Table 2 Assigned parameters for anticipated impacts of HIE for the care of patients with asthma/COPD/diabetes

	Estimated levels of reduction (%)	
Anticipated impacts	**Base case (%)**	**Sensitivity analysis range (%)**
Reducing unrequired hospitalizations due to lack of information available in the ED to make a diagnosis and disposition decision (UH)	10†	6—14
Reducing duplicative medical tests and imaging (DUP)	20*	10—30
Avoiding unnecessary ED visits though case management (AED)	30*	20—40

*Percentage of repeat ED visits (defined in the text).
†Percentage of ED visits that resulted in a hospitalization.
COPD, chronic obstructive pulmonary disease; ED, emergency department; HIE, health information exchange.

RESULTS

Three types of results were obtained with variants of our LP model:

- The *base case*, which provides the financial effects of HIE participation for each agent using benchmark estimates of changes in unnecessary hospitalizations (UH), duplicative tests, and avoidable ED visits
- Sensitivity analysis results, which measure the effects of variations in the estimates of HIE information effects used in the model
- A model that incorporates subscription and charging schemes, to determine the optimal charges for sustaining the HIE.

The first two variants (ie, base-case model and sensitivity analysis models) assumed no charging or subscription rates for HIE use and did not require that all agents benefit from the HIE (our study focused on measuring the benefits of HIE information). The third variant of our model incorporated the subscription rates and required that financial benefits accrue to all participants.

Base case

In the base case, the financial consequences of HIE participation were measured in terms of (1) absolute dollars of savings (or expenses) in our study population, diagnosed with one of the three diseases, in each of the three hospitals in our data set, and (2) percentage of the savings (or expenses) relative to the agent's budget for the care of patients in our study group.

In the base case, HIE created a societal benefit of approximately $400K per annum. Table 3 summarizes the breakdown of these benefits across each agent and highlights the financial consequences attributable to each of the three HIE effects (UH, Dup, AED) described in table 2. For example, hospital 1 can save $24 663 from HIE information, which accounts for 1.0% of their budget in caring for patients with one of the three diagnoses. The data revealed that 55% of these savings are attributed to preventing UH. For our study population, HIE data accesses produced financial gains to all agents (providers and payers).

Table 3 Effect of HIE participation on providers and payers for the care of patients with asthma/COPD/diabetes (base case)

	Savings from HIE participation		Contributing effects		
Agents	**Absolute ($)**	**Relative (%)§**	**UH (%)***	**DUP (%)†**	**AED (%)‡**
Providers					
Hospital 1	24 663	1.0	55	8	37
Hospital 2	24 571	1.1	55	3	42
Hospital 3	15 834	1.0	50	15	35
Payers					
HMO	203 531	1.4	64	0	36
Government FFS	63 120	0.3	43	11	46
Commercial FFS	75 451	2.3	56	27	16

*Unrequired ED-related hospitalizations.
†Duplicative tests and imaging on repeat ED visits.
‡Avoided repeat ED visits.
§Measured as a percentage of funds spent in the three hospitals to care for asthma/COPD/diabetes.
COPD, chronic obstructive pulmonary disease; ED, emergency department; FFS, fee-for-service; HIE, health information exchange; HMO, health maintenance organizations.

The base-case results demonstrated that, for this study population, all agents benefited from participation in the HIE and that UH was responsible for most of these savings.

Sensitivity of the model to parameters

We performed sensitivity analysis by systematically using different values of the model parameters. Effects of sensitivity analysis were evaluated on each agent as well as the system as a whole. In our study, we varied each parameter two steps in either direction from its base-case value, while maintaining the other parameters at their base-case values. Our results are summarized in figures 2–4 (note that the scales of these figures are different).

We observed (figure 2) that all agents showed a net financial gain even by minimally reducing unrequired ED-related hospitalizations. All agents except HMOs experienced gains (figure 3) at all measured rates of reduction in duplicative tests and imaging studies performed inside the ED. HMOs were not affected because the capitated fee structure ensures that medical reimbursements are independent of the number of medical procedures performed. We observed (figure 4) that HIE information should lead to more effective case management and can route patients toward more comprehensive care, thus ensuring more timely treatment and fewer emergency care visits. When tallying the effect of unrequired hospitalizations above, we do not double-count the knock-on effect of avoided ED visits. Since our model is founded on actual experience, the findings apply only to the study population.

Evaluating pricing and subscription policies

In our final sets of tests, we include the following additional constraints in the LP model:

- The HIE must break even
- The government must receive a minimum benefit of 0.3% of current spending on operations concerning the study population
- All other agents must receive a financial benefit of at least 0.5% of the total spending on operations concerning the study population.

We compare the three subscription policies in terms of: (1) absolute dollars of charge or subsidy on the set of patients diagnosed with one of the three diseases, in each of the three hospitals in our data set; (2) charge or subsidy measured as a percentage of the agent's budget for the care of patients in our study group; and (3) *look-up rate* defined as the fraction of potential patients for which a provider chooses to use the WHIE database to extract additional patient information. The *optimal look-up rate* is the look-up rate at which the hospital's profit is maximized.

The first two metrics give an insight into how a sustainable HIE must price its services. The third metric gives an insight into how the provider's use of the system affects the volume of cash flowing into the HIE.

Table 4 summarizes the subscription schemes, showing the actual charges that optimize the performance gain to the system while satisfying the constraints above. For example, the HIE should assign hospital 2 an annual charge of $14 021 (if the first charging scheme is chosen), a per-patient-per-ED visit charge of $7.15 (if the second scheme is used), or a per-look-up charge of $56.27 (for the third scheme). In all cases, it makes sense for the clinicians to look for patient-specific information in the HIE service. Our results suggest that a good strategy for institutions

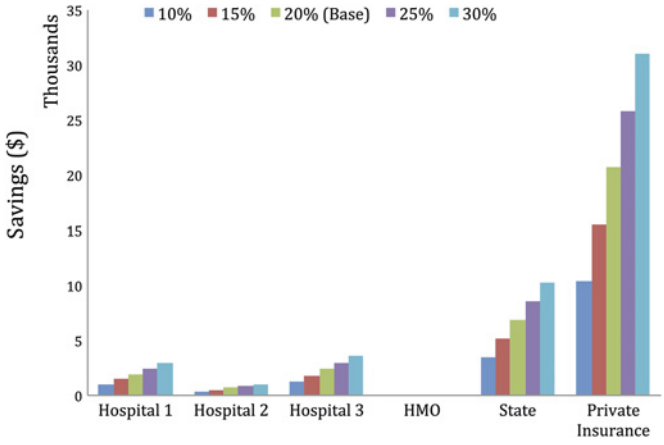

Figure 3 Effect of varying rates of reducing duplicative test and imaging inside the emergency department (DUP) on savings due to health information exchange (HIE) participation. HMO, health maintenance organizations.

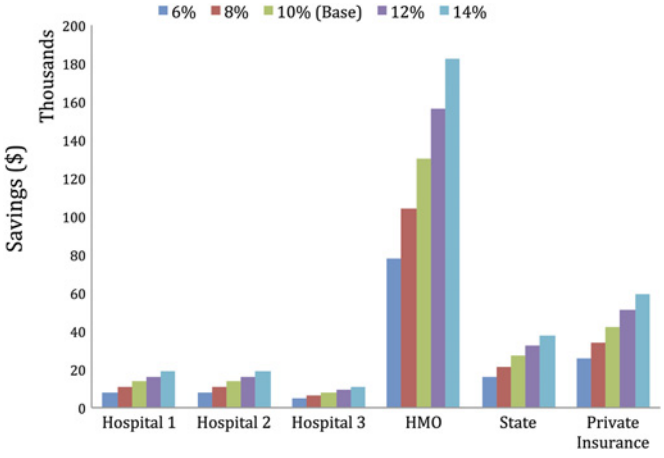

Figure 2 Effect of varying rates of reducing unrequired hospitalizations (UH) on savings due to health information exchange (HIE) participation. HMO, health maintenance organizations.

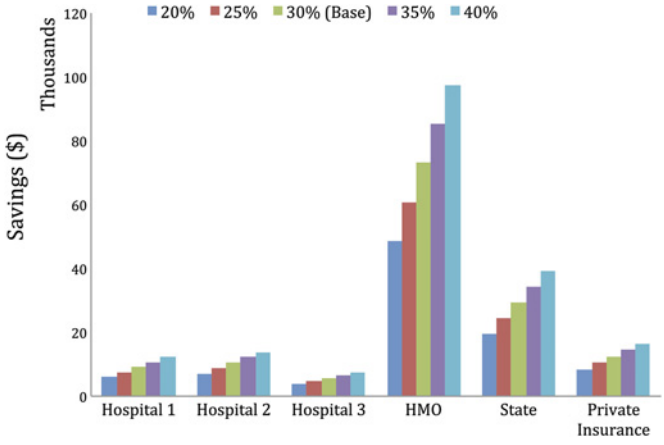

Figure 4 Effect of varying rates of avoided emergency department visits (AED) on savings due to health information exchange (HIE) participation. HMO, health maintenance organizations.

Table 4 Effect of subscription schemes on payers and providers for the care of patients with asthma/COPD/diabetes

	Subscription scheme ($) and recommended look-up rate (LR)					
	Flat annual rate		Per ED visit		Per look-up	
Providers	Charge ($)	LR (%)*	Charge ($)	LR (%)*	Charge ($)	LR (%)*
Hospital 1	12 891	100	6.25	100	35.77	34
Hospital 2	14 021	100	7.15	100	56.27	31
Hospital 3	7974	100	6.14	100	38.27	38

	Annual subscription fee‡	
Payers	Charge ($)	Charge relative to revenue (%)†
HMO	66 054	0.4
Commercial FFS	4920	0.1
Government	44 140	0.2

*Optimal look-up rate (defined in the Results section).
†Reflects only on funds spent in the three hospitals to care for asthma/COPD/diabetes.
‡Payers always pay an annual subscription fee.
COPD, chronic obstructive pulmonary disease; ED, emergency department; FFS, fee-for-service; HMO, health maintenance organizations.

is to encourage their clinicians to look up information on every patient, irrespective of the charging scheme.

DISCUSSION

We have described an LP model for evaluating the financial impact of HIE participation on a healthcare system. The model depends on parameters that capture patient demographics, costs, numbers of agents, and clinical effect of HIE information. In our study, the data were obtained from providers, payers, and public documents from a single urban region.

Our model illustrated that the HIE information benefited payers more than providers. Benefit to payers was attributed to a decrease in reimbursements because of reductions in hospitalizations and ED visits. Commercial fee-for-service (FFS) payers also benefited from a decrease in medical tests performed in the ED. We concluded from a sensitivity analysis that the financial benefits of HIE participation accrued across a wide range of parameter values and were therefore robust to imprecision in the base-case estimates.

For our dataset, HIE usage also created a benefit to providers. Although perhaps counter-intuitive, this benefit is explained by the unique payer mix of the patients in our dataset (see table 1). Providers lost money on commercial FFS patients due to a reduction in patient volume coupled with an increase in the expense-to-reimbursement ratio. However, this loss was offset by a benefit: reduced expenditure on a much larger group of Medicare/Medicaid (M/M) patients. Understanding the following three critical facts about our dataset may illuminate the source of this counter-intuitive finding:

- M/M covered four times as many patients as commercial FFS.
- Actual institutional charges for M/M patients were 25%–85% less than similarly diagnosed patients with commercial FFS insurance.
- Providers were compensated at a rate 50% lower for M/M patients than for patients in the commercial FFS population (see online appendix A).

The financial consequences described in this work, although accurate, are quite sensitive to the characteristics of the region under study.

Our model illustrated that HIE participation yielded financial benefits to all agents by enabling better care for patients who are high-volume users of the ED. Consequently, the HIE may be key for providers with increased numbers of HMO patients. Our results are consistent with the belief that an HIE benefits healthcare by reducing UH or repeated tests. Institutions considering participation in an HIE should examine how the cost of additional services, such as case management, could affect the financial bottom line.

Vest *et al*[18] noted that HIE influences clinicians' behavior through access to patient-specific information but offer no guidance on whether or not institutions should encourage this behavior. Our results demonstrated that HIE records should be consulted for every patient entering the ED, even when a per-look-up charging scheme is in place as benefits can outweigh costs for looking up medical information. Motivated by the findings of Vest *et al*,[18] online appendix C demonstrates how decision makers can use our framework to study the financial consequences for both society and agents of an individual agent's HIE implementation/usage policy. As mentioned earlier, our model can be extended beyond the three conditions considered here, provided adequate experience data can be acquired.

Our approach may have the greatest value for agents or healthcare delivery systems seeking sustainable pricing and subscription schemes for HIE use. Our model suggested that a flat annual fee for all agents is preferable. However, more data should be incorporated in the model before guidance on fee structures can be provided to support other environments.

We believe that this study is the first evaluation of an HIE that employs LP to capture the interactions between agents in a healthcare system and uses actual clinical and financial data rather than expert judgment.

Limitations

The focus throughout our research has been centered on financial benefits. We do not account for the impact of improved quality and reliability of care because these effects, while vitally important, are harder to measure. We recognize several other limitations to our work:

- We did not include start-up costs for the HIE and its users, such as interface programming and clinician training. However, with the current Office of the National Coordinator for Health Information Technology (ONC) investment in health information technology development, these costs may be low enough to not affect long-term participation decisions and sustainability requirements.
- Our model does not capture the dynamic effects, such as agents joining or leaving the HIE or hospital closures. We have used stochastic simulation to model such effects in earlier work.[19]
- Our work focused on agent-to-agent exchanges of information about a specific patient in a single care event. HIE operation modes such as direct sharing of information from home to provider or population-level data exchange will require other kinds of models.
- We did not include second-order effects such as the increased length of stay due to redundant medical work-ups.
- We do not account for behavioral issues including staff time or cognitive demand.

Conclusions

We proposed a framework, based on LP, that allows for more sophisticated analysis of the financial consequences of an HIE on each of its participating institutions. We instantiated this framework with data from three EDs to determine that: (1) HIE data accesses produced net financial gains for all participating institutions; (2) the HIE will be more important for providers

with more HMO patients; and (3) properly designed subscription schemes can sustain the HIE. The specific HIE pricing recommendations in this report apply only to the study population, but our framework can be generalized to other settings. Our framework serves not to make broad-based industry recommendations, but to allow future adopters to instantiate the model with their own experience data and explore the financial consequence of pricing policies and implementation guidelines.

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