Understanding the Economic Impact of Health Care-Associated Infections: A Cost Perspective Analysis

R. Douglas Scott II, PhD • Steven D. Culler, PhD • Kimberly J. Rask, MD, PhD

ABSTRACT

The economic impacts from preventing health care-associated infections (HAIs) can differ for patients, health care providers, third-party payers, and all of society. Previous studies from the provider perspective have estimated an economic burden of approximately $10 billion annually for HAIs. The impact of using a societal cost perspective has been illustrated by modifying a previously published analysis to include the economic value of mortality risk reductions. The resulting costs to society from HAIs exceed $200 billion annually. This article describes an alternative hospital accounting framework outlining the cost of a quality model which can better incorporate the broader societal cost of HAIs into the provider perspective.

Key words: health care-associated infections, health care cost, regulatory impact analysis, value of statistical life

Measuring the cost of health care-associated infections (HAIs) has been a challenge for health economists and health services researchers, given the lack of detailed hospital cost data needed to accurately reflect the economic value of the resources used in infection control. A 1995 review of the published research on the cost of HAIs to hospitals found that the economic evidence on cost of HAI infection control and prevention efforts was not compelling because of the variety of study designs and settings, statistical methods, and cost outcomes (length of stay vs costs) used.[1] It also has been noted that many of the methods used in the measurement of the attributable cost of HAIs were inappropriate and resulted in erroneously high-cost estimates.[2] A complicating factor for any economic analysis of HAIs is that there are divergent perspectives on the cost impacts of HAIs and who pays for them.

To help those who work as health care providers get a better understanding of the controversies surrounding the measurement of the financial and economic impact resulting from HAIs, this article will (1) review the economic theory underlying divergent cost perspectives; (2) present cost estimates for hospital-onset HAIs from varying cost perspectives, including the economic burden to the health care system and excess payments made by insurers such as Medicare; (3) introduce the societal cost perspective and the use of the value per statistical life (VSL) as used by the federal government for regulatory impact analysis; and (4) present an alternative approach to hospital accounting practices that broadens the hospital cost perspective to include the costs incurred by providers to avoid downstream patient harm.

Author Affiliations: *Centers for Disease Control and Prevention, Atlanta, Georgia (Dr Scott); and Emory University, Atlanta, Georgia (Drs Culler and Rask).*

R. Douglas Scott II, PhD, *is an economist for the Division of Healthcare Quality Promotion at the Centers for Disease Control and Prevention. His research focuses on the use of prevention effectiveness methods and regulatory impact analyses to evaluate programs to prevent health care-associated infections and improve patient safety.* **Steven D. Culler, PhD,** *is a health economist at the Rollins School of Public Health at Emory University. He has published numerous peer-reviewed articles explaining the variation in the use of health care services, estimating the incremental cost of treating selected adverse events, and performing cost-effectiveness studies.* **Kimberly J. Rask, MD, PhD,** *is a primary care physician and health economist, holding joint appointments in health policy and management and medicine at Emory University. Her publications focus on primary care practice, quality improvement, and outcomes measurement. She also serves on national expert panels on value-based purchasing programs and quality measurement.*

The authors have no conflicts of interest to disclose. The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the CDC.

Corresponding Author: *R. Douglas Scott II, PhD, Division of Healthcare Quality Promotion, National Center for Zoonotic and Emerging Infectious Diseases, Centers for Disease Control and Prevention, 1600 Clifton Road MS A16, Atlanta, GA 30329-4027 (DScott1@cdc.gov).*

DOI: 10.1097/NAN.0000000000000313

THE ANALYTICAL COST PERSPECTIVE

When a researcher begins an economic evaluation of a health care intervention or policy, he or she must first specify the point of view on which the cost analysis is based. This decision determines which benefits and costs will be included in the analysis.[3] There are 4 cost perspectives to choose from:

1. The health care provider perspective measures the costs of the resources used to prevent and/or treat patients while in their care.
2. The patient perspective includes lost work days; out-of-pocket costs for care; pain and suffering; the effect on family and/or other caregivers; long-term morbidity; and mortality.
3. The third-party payer perspective (such as Medicare) considers the excess, or shortfall, in payments made to reimburse providers for the cost of treatment for covered patients.
4. The societal perspective attempts to measure all of the costs and benefits accruing to all members of society.[4]

A review of basic economic principles will help in understanding why divergent cost perspectives in health care markets exist. The classic market structure taught in basic economic theory courses is the "perfectly competitive market," in which under the right conditions, buyers and sellers can freely interact to set a market price at which not only will the goods sold (by sellers) be equal to the amount of goods demanded (by buyers), but society will receive the greatest value for the resources used.[5] There are a number of characteristics needed for a perfectly competitive market to function properly, which include:

1. A large number of buyers and sellers willing to buy or sell the product at a certain price;
2. Perfect information, ie, all consumers and producers know the prices of all products and their value to the consumer;
3. Homogeneous products, the products made by producers, are perfect substitutes for one another;
4. A well-defined system of property rights with no externalities (the costs and benefits of a transaction affect only the well-being of the buyer and seller); and
5. No barriers to entry or exit.[5]

All of these characteristics are lacking in real-world health care markets, but the most critical missing element is perhaps perfect information. A classic paper by Kenneth Arrow[6] noted that there is "asymmetric" information between physicians and patients. This asymmetry exists because patients rely on the recommendations of physicians who have the expertise and qualifications to diagnose and treat disease. However, physicians are able to influence both the level of services that will be provided and the price patients must pay for it. In the economics literature, this is an example of the principal-agent problem.[7,8] This problem occurs when the physician (the agent), who has more information, is able to make decisions on behalf of the patient (or principal), who cannot be sure the physician is acting in his or her interests. For example, the physician is paid the same amount whether the physician chooses an effective (eg, appropriately targeted antibiotic) or an ineffective (eg, wrong-spectrum antibiotic) treatment.

HAI COSTS FROM THE HEALTH CARE SYSTEM PERSPECTIVE

The majority of economic evaluations of hospital-onset HAIs have been done from the cost perspective of a hospital or health care system and have measured direct medical treatment costs only. Economic evidence from these studies is used to make the "business case" that HAI prevention will reduce hospital costs by reducing the incidence of HAIs and the associated resources used during the excess length of stay.[9,10] However, these studies are difficult to conduct using traditional economic models of production given that hospital care is a nonstandard production process (eg, treating patients with the same diagnosis may require a different combination of tests and treatments given other comorbidities). Exacerbating the problem, the variety of cost accounting practices used by hospitals results in cost accounting data that measure costs associated with revenue-generating departments (eg, oncology, cardiac care), but lacks the details to measure treatment cost at the patient level.[11-13] As a result, most studies of attributable HAI cost use epidemiologic methods, usually retrospective cohort studies, in which patients are grouped according to whether or not they have an HAI. However, the variety of statistical methods used to analyze cohort study data leads to even more variability in HAI estimates of attributable costs.

Table 1 shows the results of a single-center study of HAI costs for a large, urban teaching hospital where the HAI attributable cost, inclusive of all infection types, was measured using several different estimation approaches including generalized linear regression, ordinary least squares (OLS) regression, OLS regression using a definition of variable cost that included physician salaries and bedside procedures; OLS models in which extremely small and large (outlier) cost values had been restricted or winsorized; propensity scoring; and a 3-state proportional hazards model estimation to measure attributable length of hospital stay (LOS) as a result of an HAI and then multiplying LOS either by the average daily cost of patients with an HAI or the daily costs of patients overall.[14] The different methods resulted in estimates of attributable cost that ranged from $9,000 to $21,000. This somewhat troubling result shows how much the selection of the estimation method can influence the amount of the estimated costs.

Recent efforts to measure the direct medical costs or the economic burden of HAIs to the health care system have been based on literature reviews. Studies by Zimlichman et al[15] and the nonpartisan and objective research organization NORC at the University of Chicago, sponsored by the Agency for Healthcare Research and Quality (AHRQ), have produced estimates of the attributable costs of select HAIs that have traditionally been the focus of surveillance and prevention efforts (Table 2).[15,16] Adjusting Zimlichman and colleagues' estimates to 2015 dollars (to match the NORC study) using the Bureau of Labor Statistics producer price index for general medical and surgical hospitals, there is

TABLE 1

Attributable Cost of a Hospital-Onset Health Care-Associated Infection[a]

Method of Measurement	Estimated Cost per Infection
Generalized linear regression model	$20,888
OLS linear regression	$19,917
OLS linear regression: total cost minus MD and procedures	$18,615
Propensity score-matched comparison	$19,251
LOS multiplied by mean HAI cost per day	$19,344
OLS linear regression; 98% Winsorized	$15,203
LOS multiplied by mean non-HAI cost per day	$15,149
3S-PHM LOS multiplied by mean HAI cost per day	$11,889
Quantile linear regression	$11,662
OLS linear regression; 95% Winsorized	$11,299
3S-PHM LOS multiplied by mean non-HAI cost per day	$9,310

Abbreviations: 3S PHM, 3-state proportional hazard model; HAI, health care-associated infection; LOS, length of hospital stay; MD, medical doctor; OLS, ordinary least squares.
[a]Inclusive of all infection types, both antibiotic susceptible or resistant, by method of measurement.
Data from Roberts et al.[14]

some agreement in the estimates for central line-associated bloodstream infections (CLABSIs) and surgical site infections, while there are differences in the estimates for ventilator-associated pneumonia, hospital-acquired antibiotic-associated *Clostridium difficile*, and catheter-associated urinary tract infections.[17] Zimlichman et al[15] estimated the annual economic burden to be approximately $10.1 billion in 2015 dollars. While the AHRQ has yet to publish economic burden estimates using the NORC attributable cost estimates, the authors' derivation of annual economic burden of these select HAIs using the NORC attributable cost estimates, along with 2014 burden estimates from the Partnership for Patients program, suggests a burden of approximately $9.3 billion in 2015 dollars.[18]

The discussion above illustrates how direct medical cost estimates for HAIs that are derived from literature reviews are sensitive to the methods used to estimate attributable costs. Readers should be aware of these limitations when considering results from any economic burden study. Additionally, studies of HAI burden of disease have tended to focus on device- or procedure-related infections because surveillance systems typically do not track non–device- or non–procedure-related HAIs in acute care hospitals.[19] A recent study does provide burden estimates for all HAI types, but because the study sample of hospitals was small, there is significant variability in the estimates, adding even more variability in the economic burden estimates.[19]

THIRD-PARTY PAYER PERSPECTIVE

When considering the cost perspective of a third-party payer, it's important to distinguish reimbursements from direct medical costs. Economic evaluation methods, including cost-benefit analysis and cost-effectiveness analysis, require that the monetary valuation of all inputs associated with an intervention or program be based on the actual consumption of resources used as program inputs.[20] The direct medical costs of medical treatments and policies reflect the economic value of the resources used in the treatment of patients, such as labor, procedures performed, number of laboratory tests, and more. Reimbursements are payments made to hospitals by third parties, ie, insurance companies, on behalf of patients who are policy holders. The amount of these payments has been negotiated between the hospital and the insurer, either a private-sector company or a government program—ie, Medicare and Medicaid—for their patients who have purchased coverage. These payments can be referred to as *transfer payments* because they do not involve any additional consumption of medical resources.[21,22]

Because transfer payments are not costs, the impacts of HAIs on third-party payer reimbursements would not be included in a cost evaluation taken from either the health care provider or the societal cost perspective. However, insurance companies have an incentive to minimize reimbursements—particularly Medicare and its Part A insurance program, which covers hospitalizations—and they can

TABLE 2

Estimates of Attributable HAI Cost Estimates From Literature Reviews

HAI Type	Zimlichman et al[15]	NORC Report[16]
Catheter-associated urinary tract infections	$924	$13,793
Central line-associated bloodstream infections	$47,254	$48,108
Surgical site infections	$21,438	$28,219
Ventilator-associated pneumonia	$41,406	$47,238
Hospital-acquired antibiotic-associated *Clostridium difficile*	$11,640	$17,260

Abbreviation: HAI, health care-associated infection; NORC, the nonpartisan and objective research organization NORC at the University of Chicago.

conduct economic evaluations of HAI prevention programs to determine any effect on their budgets. Researchers at the Centers for Disease Control and Prevention (CDC) have conducted a number of studies that take the third-party payer perspective, specifically Medicare. Results from these studies have found that (1) the excess Medicare reimbursement for a CLABSI in intensive care units (ICUs) was $25,000; (2) the excess Medicare reimbursement for a catheter-associated urinary tract infection was $8,500 in ICU patients and $1,500 for patients in non-ICU wards; and (3) implementation of a multifaceted infection control and antibiotic stewardship program to prevent *C difficile* is predicted to save $2.5 billion in Medicare reimbursements over a 5-year period.[23-25] Consistent with the third-party payer cost perspective, cost impacts on patients (ie, additional out-of-pocket costs, lost wages, productivity losses, etc) are ignored in these studies.

SOCIETAL COST PERSPECTIVE AND VSL

The societal cost perspective includes the cost and benefits to all members of society. It is challenging to measure the economic impact of long-term sequelae, such as amputations or stays in long-term facilities; lost labor productivity; premature death; intangible costs, such as lost leisure time or disability; and patient out-of-pocket costs. There are few clinical data on the magnitude of these outcomes for patients suffering an HAI. One attempt to measure HAI costs from a societal perspective was carried out by Marchetti and Rossiter.[26] They found that the annual direct medical costs of hospital HAIs ranged from $34 billion to $74 billion, while the additional social costs of HAIs, which included lost wages for incapacitation and premature death, ranged from $62 billion to $73 billion (Table 3). The value of lost wages was derived from a survey of judgments in liability cases where the value of lost productivity averaged $685,225. Adding in these costs increased the total societal cost estimate, which ranged from $96 billion to $147 billion a year.

As an alternative to using lost wages and liability judgments in valuing the cost of premature death, federal government regulatory agencies have a long history of using the VSL in regulatory impact analyses that affect human health and mortality.[27] The VSL is the value an individual will place on a marginal change in the likelihood of their death. For example, consider a population of 100 000 in which it has been determined that each person would be willing to pay an average of $50 to reduce their risk of dying by 1/100 000. Here, the VSL is equal to $50 ÷ (1/100 000) or $5 million, which is the estimated value that society would pay to reduce the risk of 1 person dying.[27] In practice, the VSL is measured in 2 ways: (1) wage studies that examine wage differentials for jobs with varying levels of job-related risks, or (2) survey methods in which respondents are asked what they would be willing to pay for changes in their risk of death.

The range of VSL estimates currently used by the Department of Health and Human Services is $4.4 million (low), $9.3 million (central), and $14.2 million (high), based on 2014 dollars and income level.[28] To calculate the economic value of mortality risk reductions, we must also have an estimate of the number of deaths that are attributable or the result of acquiring an HAI. Some studies estimate that, among patients with *Acinetobacter* infection, methicillin-resistant *Staphylococcus aureus* infection, *C difficile* infection, and CLABSI, the proportion of mortality attributable to the infection can range from 50% to 70%. There is limited evidence on the proportion of mortality attributable to other HAIs that are not associated with antibiotic resistance or medical devices or procedures.[29-32] If the low and high VSL estimates were substituted in Marchetti and Rossiter's study[26] and it was conservatively assumed that the overall proportion of mortality among patients with HAIs attributable to the infection was 40% (ie, 39 595 of the 98 987 premature deaths noted in the study), the additional social benefits would range from $174 billion to $562 billion a year, increasing the overall societal benefits, including direct costs, to a range of $208 billion to $636 billion (Table 4). The economic value of mortality risk reductions is significantly larger—5 to 7 times larger—than the reduced direct medical costs alone.

TABLE 3

Societal Cost of Hospital-Acquired Infections[a]

Category	Societal Low	Societal High
Direct costs (billions, 2010)		
Index hospitalization	$24.8	$53.9
Professional fees index hospitalization	$4.9	$13.2
Postdischarge outpatient	$0.2	$0.2
Readmission postindex hospitalization	$3.4	$4.0
Professional fees readmission	$0.7	$1.0
Postdischarge diagnosed infection	$0.3	$1.7
Subtotals	$34.3	$74.0
Indirect costs (billions, 2010)		
Lost wages, incapacitation ($149 a day)	$2.5	$3.9
Lost future wages, premature death ($685,225)	$59.1	$68.7
Subtotals	$61.6	$72.6
Totals	$95.9	$146.6

[a]Data from Marchetti and Rossiter.[26]

A HOSPITAL COST MODEL THAT INCORPORATES DOWNSTREAM PATIENT IMPACT

The full social and economic impact of HAIs on patients can be ignored by hospitals because hospitals are not affected by many of the costs incurred by patients who

TABLE 4

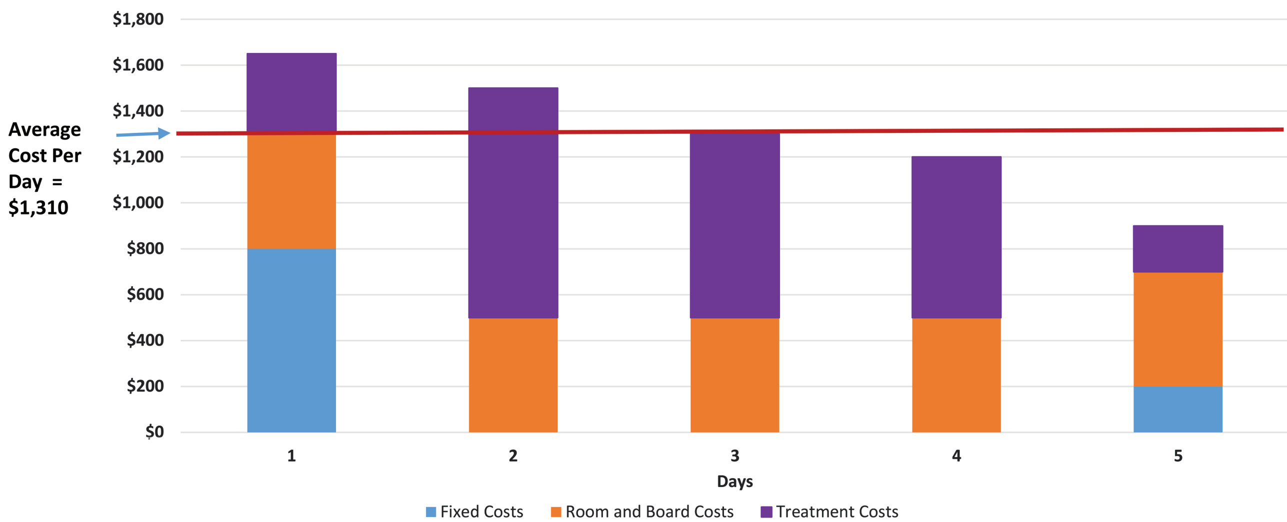
Direct Cost of Associated Hospital-Onset HAI and HHS VSL

Measure	Number of Attributable Mortality Cases	Per Patient VSL and Cost Estimates	Total Costs
Value of mortality risk reductions[a]	39 595	$4.4 million (low) $14.2 million (high)	$174 billion–$562 billion
Direct medical costs[b] (from Table 3)	1 453 077 (low) 1 676 628 (high)	$17,070 (low) $32,176 (high)	$34.3 billion–$74 billion
Total societal costs			$208.3 billion–$636 billion

Abbreviations: HAI, health care-associated infection; HHS, US Department of Health and Human Services; VSL, value of statistical life.
[a]Data from Scott et al.[23]
[b]Data from Marchetti and Rossiter.[26]

suffer an HAI. There is a managerial costing framework that can better incorporate the downstream economic consequences faced by patients who contract an HAI. The cost-of-quality (CoQ) model is a framework in which all of the resources used to achieve product quality are included, which in this case is quality of care in terms of preventable HAIs. The CoQ model makes explicit that all costs associated with HAI prevention, including infection control programs, hand hygiene protocols, environmental and housekeeping services, and sterilization services, must be counted along with the additional treatment costs of HAIs. The classical model for costing quality is the prevention-appraisal-failure (PAF) model.[33-35] The model can be expressed more formally as (1) CoQ = appraisal costs + prevention costs + internal failure costs + external failure costs.

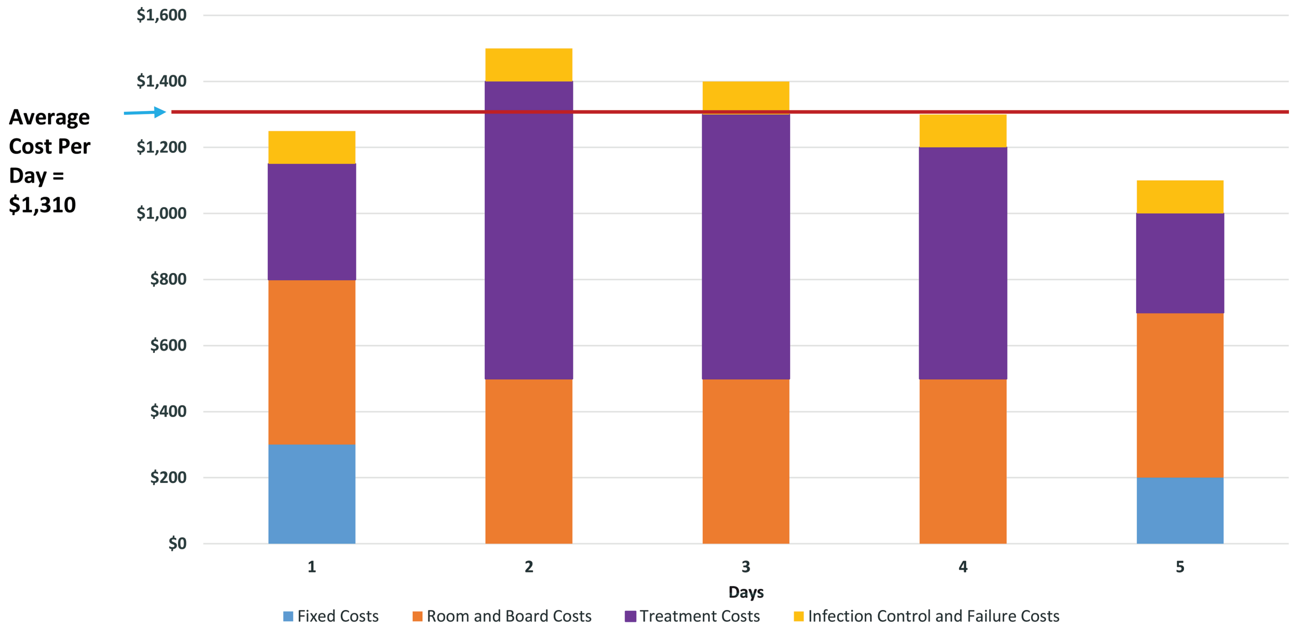
In this model, when an HAI occurs, the total cost is not only the treatment cost of an HAI (internal failure costs) but also the costs associated with appraisal (surveillance and management) and prevention (infection control interventions). Costs associated with insurance premiums and any liability judgments paid by hospitals would also be included (external failure costs). Hospitals with poor or excellent performance in preventing HAIs could also lose or gain market share as the result of the impact on their reputation, which is another external failure cost. Figure 1 presents a hypothetical distribution of daily hospital costs for patients in the diagnosis-related group (DRG) for those with diabetes and complicating conditions (DRG 638) and an average length of stay of 5 days. Fixed costs (in blue) are charged on day 1 and day 5, including administrative fees (eg, creating



Data Table

	Days					
Cost Category	**1**	**2**	**3**	**4**	**5**	**Total**
Fixed costs	$800	$0	$0	$0	$200	$1,000
Room and board costs	$500	$500	$500	$500	$500	$2,500
Treatment costs	$350	$1,000	$800	$700	$200	$3,050
Total	**$1,650**	**$1,500**	**$1,300**	**$1,200**	**$900**	**$6,550**

Figure 1 Hypothetical distribution of daily patient costs.



Data Table

	Days					
Cost Category	**1**	**2**	**3**	**4**	**5**	**Total**
Fixed costs	$300	$0	$0	$0	$200	$500
Room and board costs	$500	$500	$500	$500	$500	$2,500
Treatment costs	$350	$900	$800	$700	$300	$3,050
Infection prevention and failure costs	$100	$100	$100	$100	$100	$500
Total	**$1,250**	**$1,500**	**$1,400**	**$1,300**	**$1,100**	**$6,550**

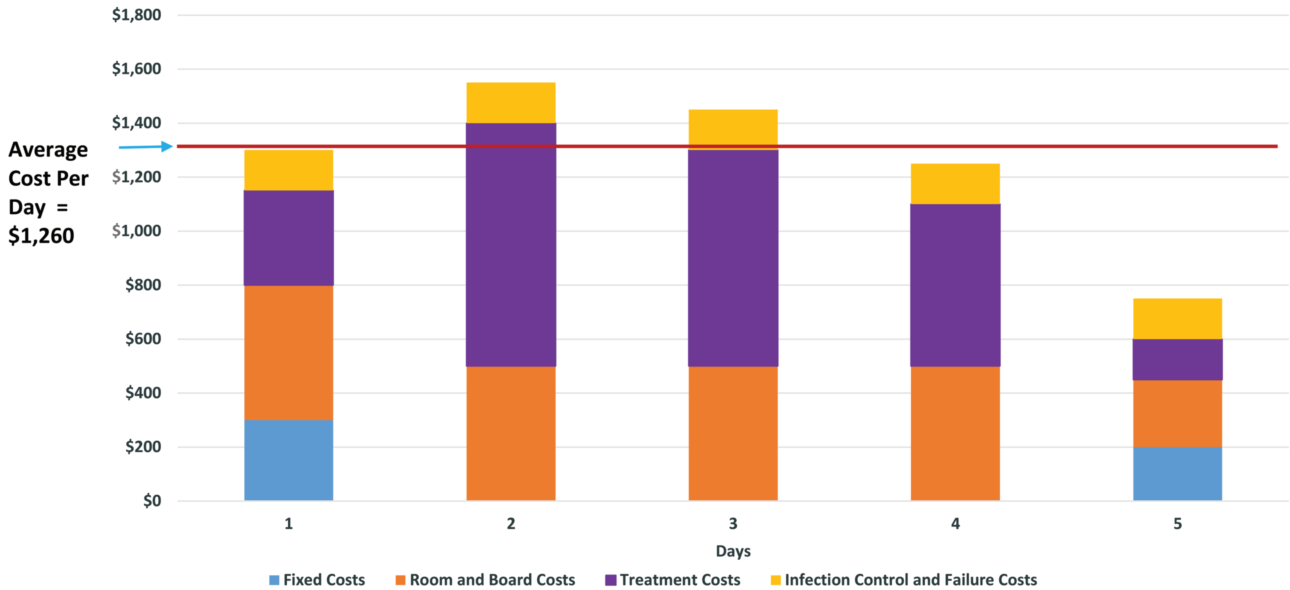
Figure 2 Hypothetical distribution of daily hospital costs, including infection prevention and failure costs.

a patient's record) and services, such as infection control (for day 1), and discharge fees (day 5); daily hospital room and board costs (orange) and daily treatment costs (purple) vary across the 5 days. Within this DRG patient group, it costs the hospital an average of $6,550 for each patient's care.[36] The average daily cost of $1,310 ($6,550/5) is represented by the horizontal line.

In the CoQ model, activity-based accounting practices would identify the daily charges associated with infection prevention, including the infection control program, housekeeping/environmental services, sterilization, and all other prevention activities, as well as the failure costs associated with treatment of HAIs, insurance premiums, and reputation costs. In Figure 2, the costs of infection prevention activities plus failure costs are explicitly accounted for on a daily basis (in yellow). For day 1, fixed costs are now reduced by $500 because the costs related to infection control are now allocated on a per day basis ($100) across the 5 days.

Now it is possible for the accounting system to assess how increasing investments in infection control can produce savings through reduced treatment costs and hospital room and board costs. If the hospital increases its investment in infection control appraisal and/or prevention programs that are both effective and cost saving by 50% ($250 or $50 a day), the impact would look like Figure 3. For this example, the increased investment results in a decrease in average treatment costs on days 4 and 5 ($100 and $150, respectively) and a savings of $250 in hospital room and board, as the average length of stay decreases from 5 days to 4.5 days (Figure 2). The total cost savings of $500, minus the additional $250 in increased infection control costs, results in an overall decrease in average patient cost of $250, for a total of $6,300. Now all the average daily costs across the 5 days, which declines to $1,260 ($6,300/5) a day, are covered by the average daily DRG payment. In 2015, cases designated with DRG 638 received an average total payment of $6,593 (Medicare reimbursement and other copayments from patients or other insurers). Before the investment in infection control, the hospital's net revenue per patient was $43.[36] In this example, the additional expenditures in infection control resulted in an additional $250 in patient cost savings and increased net per patient revenue to $293.

To apply the CoQ model, most hospital accounting systems would have to be redesigned. To start, an activity-based accounting identity for infection control would have to be created to assess the total cost of an infection control program. An activity-based account for infection control should include most of the budgets for environmental services (housekeeping); central services and supply; laundry services; the cost of the infection control



Data Table

Cost Category	Days 1	2	3	4	5	Total
Fixed costs	$300	$0	$0	$0	$200	$500
Room and board costs	$500	$500	$500	$500	$250	$2,250
Treatment costs	$350	$900	$800	$600	$150	$2,800
Infection control and failure costs	$150	$150	$150	$150	$150	$750
Total	**$1,300**	**$1,550**	**$1,450**	**$1,250**	**$750**	**$6,300**

Figure 3 Hypothetical distribution of daily hospital costs, including new level of investment in infection prevention.

program; labor costs associated with HAI prevention education, hand hygiene practices, and contact precautions; any capital costs related to infection control, ie, number of airborne infection isolation rooms; insurance premiums and other risk management practices; and any other costs associated with materials and supplies used for current infection prevention interventions. Based on the 2015 Medicare hospital cost reports, the annual budgets for housekeeping, laundry, and central services averaged $1,730,000, $433,000, and $2,370,000, respectively.[37] From a 2008 estimate, the average annual cost of a hospital infection control program, when adjusted to 2015 dollars, is approximately $288,000.[23,38] Adding these expenditures, the annual cost of infection control for an average hospital in 2015 is approximately $4.8 million.

A challenge with activity-based costing is that the data needs for a hospital's accounting system are greater, and these systems are costlier to implement and maintain administratively. For example, to understand the labor costs associated with hand hygiene, a hospital must measure the labor time needed to comply with the hospital's hand hygiene guidelines across the spectrum of employees required to comply. Any purchases of supplies and materials for infection control must be transferred from the facilities and maintenance budget to the infection control activity. However, new modifications to the activity-based accounting model (ie, time-driven, activity-based costing) have reduced data needs and have been used to identify the actual cost of care for operational improvements, reducing costs while maintaining quality, and to inform reimbursement policy.[39-41] In addition, the Centers for Medicare and Medicaid Services' (CMS') efforts to move to bundled payments for selected episodes of care will encourage hospitals and other providers to enhance their cost accounting to understand the true resource cost of providing care for selected types of patients.

Since 2015, hospitals have been subject to financial penalties from Medicare through the Hospital-Acquired Condition (HAC) Reduction Program.[42] Under this program, Medicare reduces total inpatient reimbursements by 1% for the lowest-performing 25% of hospitals, based on a set of HAC measures that includes HAIs.[43] In fiscal year 2016, 769 hospitals were penalized an average of $560,000 under this program.[44] Given the potential benefits to patients, families, the health system, and society from HAI prevention, the costs of improved accounting practices are trivial.

CONCLUSION

Understanding the cost perspective used in economic studies of HAIs is critical to interpreting the results. Results from economic studies of HAI prevention programs using the hospital perspective have produced attributable cost estimates that exceed $9 billion a year. Economic studies of HAI cost from the Medicare perspective show that the attributable costs to third-party payers are substantial. When taking a societal cost perspective, adding the economic value of mortality risk reductions significantly increases the realized benefits from HAI prevention by better capturing all of the patient costs incurred. In the example used here, the benefits of mortality risk reductions were at least 5 times greater than the benefits resulting from the reduction in the direct medical costs to hospitals alone. Federal agencies, such as CMS, the CDC, and AHRQ, as well as almost every state in the country, already have recommendations and/or regulatory standards that require hospitals to decrease infection based on evidence-based practices.[45-47] While a federal rule requiring hospitals to institute antibiotic stewardship programs has been proposed but not finalized, the state legislatures of California and Missouri have already passed statutes requiring hospitals to implement antibiotic stewardship programs.[48-50] Future economic evaluations that incorporate the value of morbidity and mortality risk reductions associated with HAI prevention programs will provide a more comprehensive assessment of the societal benefit resulting from these interventions.

Given the current structure of health care markets, the societal economic benefits of reducing HAIs are not reflected in the cost and resource allocation decisions facing hospitals. Using the CoQ model can help hospitals incorporate more of the costs incurred by patients that are not currently accounted for by traditional hospital accounting methods. The model also makes it explicit that when an HAI occurs, the cost to the hospital includes not only the costs of treatment but also the costs of prevention and surveillance efforts. To minimize costs, hospital administrators should strive to avert HAIs, but do so using prevention resources as efficiently as possible.

ACKNOWLEDGMENTS

This paper is a revised and extended version of a presentation that was given at the Infusion Nurses Society's National Academy 2017, in Atlanta, Georgia, on November 4, 2017. The authors would like to thank the reviewers for their helpful comments.

REFERENCES

1. Stone PW, Larson E, Kawar LN. A systematic audit of economic evidence linking nosocomial infections and infection control interventions: 1990-2000. *Am J Infect Control*. 2002;30(3):145-152.
2. Graves N, Harbarth S, Beyersmann J, Barnett A, Halton K, Cooper B. Estimating the cost of health care-associated infections: mind your p's and q's. *Clin Infect Dis*. 2010;50(7):1017-1021.
3. Russell LB, Siegel JE, Daniels N, et al. Cost-effectiveness analysis as a guide to resource allocation in health: roles and limitations. In: Gold MR, Siegel JE, Russell LB, Luce BR, Mandelblat JS, eds. *Cost-Effectiveness in Health and Medicine*. New York, NY: Oxford University Press; 1996:3-24.
4. Farnham PG, Haddix AC. Study design. In: Haddix AC, Teutsch SM, Corso PS, eds. *Prevention Effectiveness: A Guide to Decision Analysis and Economic Evaluation*. New York, NY: Oxford University Press; 2003:11-27.
5. Baumol WJ, Blinder AS. *Economics: Principles and Policy*. 12th ed. Mason, OH: South-Western; 2012.
6. Arrow KJ. Uncertainty and the welfare economics of medical care. *Am Econ Rev*. 1963;53(5):941-973.
7. Mooney G, Ryan M. Agency in health care: getting beyond first principles. *J Health Econ*. 1993;12(2):125-135.
8. Blomqvist A. The doctor as double agent: information asymmetry, health insurance, and medical care. *J Health Econ*. 1991;10(4):411-432.
9. Stone PW, Hedblom EC, Murphy DM, Miller SB. The economic impact of infection control: making the business case for increased infection control resources. *Am J Infect Control*. 2005;33(9):542-547.
10. Perencevich EN, Stone PW, Wright SB, et al. Raising standards while watching the bottom line: making a business case for infection control. *Infect Control Hosp Epidemiol*. 2007;28(10):1121-1133.
11. Player S. Activity-based analyses lead to better decision making. *Healthc Financ Manage*. 1998;52(8):66-70.
12. Kaplan RS, Porter ME. How to solve the cost crisis in health care. *Harv Bus Rev*. 2011;89(9):46-52, 54, 56-61.
13. Palsis JA, Brehmer TS, Pellegrini VD, Drew JM, Sachs BL. The cost of joint replacement: comparing two approaches to evaluating costs of total hip and knee arthroplasty. *J Bone Joint Surg Am*. 2018;100(4):326-333.
14. Roberts RR, Scott RD 2nd, Hota B, et al. Costs attributable to healthcare-acquired infection in hospitalized adults and a comparison of economic methods. *Med Care.* 2010;48:1026-1035.
15. Zimlichman E, Henderson D, Tamir O, et al. Health care-associated infections: a meta-analysis of costs and financial impact on the US health care system. *JAMA Intern Med*. 2013;173(22):2039-2046.
16. Bysshe T, Gao Y, Heaney-Huls K, et al. Final report: estimating the additional hospital inpatient cost and mortality associated with selected hospital-acquired conditions. Agency for Healthcare Research and Quality website. AHRQ publication no. 18-0011-EF. https://www.ahrq.gov/sites/default/files/wysiwyg/professionals/quality-patient-safety/pfp/hac-cost-report2017.pdf. Published November 2017. Accessed October 29, 2018.
17. Bureau of Labor Statistics. Producer price indexes. https://www.bls.gov/ppi. Accessed October 26, 2018.
18. Agency for Healthcare Research and Quality. National scorecard on rates of hospital-acquired conditions 2010 to 2015: interim data from national efforts to make health care safer. https://psnet.ahrq.gov/resources/resource/30706/national-scorecard-on-rates-of-hospital-acquired-conditions-2010-to-2015-interim-data-from-national-efforts-to-make-health-care-safer. Posted December 2016. Accessed October 26, 2018.
19. Magill SS, Edwards JR, Bamberg W, et al. Multistate point-prevalence survey of health care-associated infections. *N Engl J Med*. 2014;370(13):1198-1208.
20. Drummond MF, Sculpher MJ, Torrance GW, O'Brian BJ, Stoddart GL. *Methods for the Economic Evaluation of Health Care Programmes*. 3rd ed. New York, NY: Oxford University Press; 2005.
21. Muennig P. *Designing and Conducting Cost-Effectiveness Analyses in Medicine and Health Care*. San Francisco, CA: Jossey-Bass; 2002.
22. Frisman L, Rosenheck R. How transfer payments are treated in cost-effectiveness and cost-benefit analyses. *Adm Policy Ment Health*. 1996;23(6):533-546. doi:10.1007/BF02108689.
23. Scott RD II, Sinkowitz-Cochran R, Wise ME, et al. CDC central-line bloodstream infection prevention efforts produced net benefits of at least $640 million during 1990-2008. *Health Aff (Millwood)*. 2014;33(6):1040-1047.
24. Yi SH, Baggs J, Gould CV, Scott RD 2nd, Jernigan JA. Medicare reimbursement attributable to catheter-associated urinary tract infection

in the inpatient setting: a retrospective cohort analysis. *Med Care*. 2014;52(6):469-478.

25. Slayton RB, Scott RD, Baggs J, Lessa FC, McDonald LC, Jernigan JA. The cost-benefit of federal investment in preventing clostridium difficile infections through the use of a multifaceted infection control and antimicrobial stewardship program. *Infect Control Hosp Epidemiol*. 2015;36(6):681-687.
26. Marchetti A, Rossiter R. Economic burden of health care-associated infection in US acute care hospitals: societal perspective. *J Med Econ*. 2013;16(12):1399-1404.
27. Robinson LA. How US government agencies value mortality risk reductions. *Rev Environ Econ Policy*. 2007;1(2):283-299.
28. US Department of Health and Human Services. Guidelines for regulatory impact analysis. https://aspe.hhs.gov/pdf-report/guidelines-regulatory-impact-analysis. Published January 13, 2017. Accessed October 26, 2018.
29. Nelson RE, Slayton RB, Stevens VW, et al. Attributable mortality of healthcare-associated infections due to multidrug-resistant gram-negative bacteria and methicillin-resistant Staphylococcus aureus. *Infect Control Hosp Epidemiol*. 2017;38(7):848-856.
30. Nelson RE, Schweizer ML, Perencevich EN, et al. Costs and mortality associated with multidrug-resistant healthcare-associated Acinetobacter infections. *Infect Control Hosp Epidemiol*. 2016;37(10):1212-1218.
31. Tabak YP, Zilberberg MD, Johannes RS, Sun X, McDonald LC. Attributable burden of hospital-onset Clostridium difficile infection: a propensity score matching study. *Infect Control Hosp Epidemiol*. 2013;34(6):588-596.
32. Stevens V, Geiger K, Concannon C, Nelson RE, Brown J, Dumyati G. Inpatient costs, mortality and 30-day re-admission in patients with central-line-associated bloodstream infections. *Clin Microbiol Infect*. 2014;20(5):O318-O324.
33. Feigenbaum AV. Total quality control. *Harv Bus Rev*. 1956;34(6):93-101.
34. Juran JM. Quality Control Handbook. New York, NY: McGraw-Hill; 1951.
35. Porter LJ, Rayner P. Quality costing for total quality management. *Int J Prod Econ*. 1992;27(1):69-81. doi:10.1016/0925-5273(92)90127-S.
36. Centers for Medicare and Medicaid Services. Inpatient charge data FY 2015. https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/Medicare-Provider-Charge-Data/Inpatient2015.html. Updated March 1, 2018. Accessed October 29, 2018.
37. Centers for Medicare and Medicaid Services. Cost reports: details for title: 2015. https://www.cms.gov/Research-Statistics-Data-and-Systems/Downloadable-Public-Use-Files/Cost-Reports/Cost-Reports-by-Fiscal-Year-Items/HOSPITAL10-DL-2015.html?DLPage=7&DLEntries=10&DLSort=0&DLSortDir=ascending. Accessed October 29, 2018.
38. Bureau of Labor Statistics. CPI inflation calculator. https://www.bls.gov/data/inflation_calculator.htm. Accessed October 29, 2018.
39. Kaplan RS, Anderson SR. Time-driven activity-based costing. *Harv Bus Rev*. 2004;82(50):131-138, 150.
40. Keel G, Savage C, Rafiq M, Mazzocato P. Time-driven activity-based costing in health care: a systematic review of the literature. *Health Policy*. 2017;121(7):755-763.
41. Beriwal S, Chino J. Time-driven activity-based costing in oncology: a step in the right direction. *Int J Radiat Oncol Biol Phys*. 2018;100(1):95-96.
42. Centers for Medicare and Medicaid Services. Hospital-acquired condition reduction program (HACRP). https://www.cms.gov/Medicare/Medicare-Fee-for-Service-Payment/AcuteInpatientPPS/HAC-Reduction-Program.html. Updated July 30, 2018. Accessed October 29, 2018.
43. *Report to the Congress: Medicare Payment Policy*. Washington, DC: Medicare Payment Advisory Commission; 2017. http://medpac.gov/docs/default-source/reports/mar17_entirereport224610adfa9c665e80adff00009edf9c.pdf?sfvrsn=0. Published March 15, 2017. Accessed October 29, 2018.
44. Rau J. Latest hospital injury penalties include crackdown on antibiotic-resistant germs. Kaiser Health News. https://khn.org/news/latest-hospital-injury-penalties-include-crackdown-on-antibiotic-resistant-germs. Published December 21, 2016. Accessed October 29, 2018.
45. US Department of Health and Human Services. Office of Disease Prevention and Health Promotion. National action plan to prevent health care-associated infections: road map to elimination. https://health.gov/hcq/prevent-hai-action-plan.asp. Updated October 29, 2018. Accessed October 29, 2018.
46. The White House. National action plan for combating antibiotic-resistant bacteria. https://health.gov/hcq/prevent-hai-action-plan.asp. Published March 2015. Accessed October 29, 2018.
47. Centers for Disease Control and Prevention. State-based HAI prevention. https://www.cdc.gov/hai/state-based/index.html. Updated July 25, 2016. Accessed October 29, 2018.
48. Centers for Medicare and Medicaid Services. CMS issues proposed rule that prohibits discrimination, reduces hospital-acquired conditions, and promotes antibiotic stewardship in hospitals. https://www.cms.gov/newsroom/fact-sheets/cms-issues-proposed-rule-prohibits-discrimination-reduces-hospital-acquired-conditions-and-promotes. Published June 13, 2016. Accessed October 29, 2018.
49. California Department of Public Health. Health care-associated infections (HAI) program: California antimicrobial stewardship program initiative. https://www.cdph.ca.gov/Programs/CHCQ/HAI/Pages/CA_AntimicrobialStewardshipProgramInitiative.aspx. Updated August 22, 2018. Accessed October 29, 2018.
50. Missouri Hospital Association. New state laws in 2016: looking ahead. https://web.mhanet.com/Regulatory/Inside%20Track/2016/Regulatory_Review_NewLawsIn2016.pdf. Accessed October 29, 2018.