

Estimates of Costs for Housing-Related Interventions to Prevent Specific Illnesses and Deaths

Jacquelyn Mason, MS, PhD; Mary Jean Brown, ScD, RN

Public health is embracing economic analyses in an effort to use limited resources in the most efficient manner. However, users of economic analyses in the public health arena should recognize the inherent strengths and weaknesses of different types of analysis, as well as understand how the inclusion or omission of certain costs or benefits might influence study results. For example, asthma is a chronic condition that can result in health care costs that accrue well beyond the duration of a housing intervention. Thus, an economic analysis that omits long-term health care costs can underestimate the total economic benefit of the housing intervention. This article contains reviews of economic articles on housing interventions published in PubMed, examines salient differences between studies, and discusses pertinent gaps in the literature. In addition, this article attempts to provide an overview of key economic evaluation methods in relation to housing interventions to a target audience of local and state public health practitioners. Specific housing-related health issues discussed include asthma, lead, and carbon monoxide poisoning and radon-related lung cancer.

KEY WORDS: cost-benefit analysis, cost-effectiveness analysis, economic analysis, economic evaluation, economics, healthy housing

A growing body of research has estimated the numbers of people who become ill or die because of unhealthy housing. The research also has provided estimates of the effectiveness of housing interventions to eliminate or reduce these adverse health outcomes. However, few studies compare the economic burden of housing-related adverse health outcomes

with the resources required to implement relevant interventions. Public health practitioners should use economic analyses to guide decisions regarding the efficient use of resources.^{1,2}

This article gives an overview of economic analyses commonly used in public health, examines the economic burden of housing-related illness, and compares economic studies that focus on housing-related illness and associated interventions. Examples are given to discuss the appropriate interpretation of findings from economic studies and to help guide decision making regarding implementation of housing-related interventions to improve health. Specific housing-related health issues discussed include asthma and adverse effects from lead, radon, and carbon monoxide (CO). The economic costs and burden of common housing-related injuries are excluded from this article and will be the subject of a separate subsequent analysis. The work did not involve human subjects.

● Overview of Economic Analysis Methods

Five types of economic analysis methods are common in the public health literature:

- Cost of illness (COI)
- Cost analysis (CA)
- Cost-effectiveness analysis (CEA)

Author Affiliation: Division of Emergency and Environmental Health Services, National Center for Environmental Health, Centers for Disease Control and Prevention, Atlanta, Georgia.

Disclaimer: The findings and conclusions presented here are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

The authors thank Ginger Chew, Paul Garbe, Scott Gross, Pamela Meyer, Tursynbek Nurmagambetov, David Sleet, and Will Wheeler for helpful comments.

Correspondence: Jacquelyn Mason, MS, PhD, Centers for Disease Control and Prevention, 4770 Buford Hwy, MS-F60, Atlanta, GA 30341 (zao4@cdc.gov).

- Cost-utility analysis (CUA)
- Cost-benefit analysis (CBA)

Cost-of-illness studies convey the magnitude of a public health problem in monetary terms. The summary measure of a COI analysis includes all costs (ie, medical, nonmedical, and productivity) associated with all adverse health outcomes resulting from a health problem.³ In contrast, a “program” CA quantifies the value of resources required to implement 1 or more interventions. This type of analysis may include not only costs associated with implementing the intervention but also costs that are saved as a result of the intervention. In the latter case, results from the CA are presented as net costs (ie, COI minus total program costs).⁴

Cost-of-illness studies and cost analyses that focus on a single program are inherently descriptive in nature—they are conducted to describe the economic burden of a disease or illness or the costs and potential cost savings associated with implementing an intervention.⁵ Economic *evaluation* analyses, in contrast, go beyond merely quantifying illness-associated or intervention implementation costs to comparing the costs and effects of alternative intervention strategies. In public health, the most common of these economic evaluation approaches is CEA.³ The summary measure of CEA is a ratio of net cost of the intervention (program cost minus costs saved because of adverse health conditions prevented) per improvement in health resulting from the intervention (eg, cost per case averted or cost per symptom-free day).^{3,5,6} Alternatives under consideration may include another intervention, “usual care,” or the “do nothing” option.⁷ When alternative strategies intended to address the same health outcome are being compared, the alternatives can be ranked on the basis of their cost-effectiveness ratio. Cost-effectiveness analysis is typically performed to compare the relative efficiency of 2 or more interventions, that is, to determine the relative bang for the buck of each intervention.² Under these circumstances, the incremental cost-effectiveness ratio is reported. The incremental cost-effectiveness ratio is the additional cost per additional unit of health effect resulting from the intervention under study as compared with the next best alternative.⁷ Unless an intervention is both more effective and less costly than all alternatives, the determination of whether an intervention is cost-effective assumes a threshold exists for which the health benefits gained are judged by decision makers to be large enough to justify the additional cost of the intervention,⁸ although there is some controversy surrounding the use of such thresholds.⁵

Cost-utility analysis is technically a special case of CEA.^{3,5,7} What distinguishes CUA from CEA is that the

health outcome measure, typically quality-adjusted life years (QALY), accounts for both the prolongation and quality of life.^{5,7} A QALY is a health outcome that incorporates preferences for different health states, where 1 is perfect health and 0 is death. While the QALY is the predominant generic outcome measure used in CUAs, alternative outcome measures have been proposed. For example, the World Health Organization recommends the use of disability-adjusted-life-years in CUAs.⁹ Because the outcome measure in a CUA captures the multifaceted nature (ie, both length and quality of life) of health outcomes and therefore allows disparate health conditions and interventions to be compared, a number of health economists recommend CUA be conducted as part of any economic analysis.^{1,7} This recommendation notwithstanding, some researchers note that QALYs can be subjective, are not available for many health outcomes, can be difficult to measure, and may not be universally accepted.³

Some researchers suggest CBA as the gold standard of economic evaluation methods.³ A CBA compares the costs and consequences (both positive and negative) of disparate intervention strategies in monetary terms. It can be useful in choosing among competing program options, helping to decide whether to implement a program, and setting priorities within resources constraints.^{3,6} For example, CBA is the primary form of economic evaluation used in regulatory analyses, including regulations relating to housing and environmental health.² The summary measure of a CBA is expressed as either net benefit (ie, costs minus benefits) or as a ratio of costs to benefits. In CBA, “benefits” comprise the economic value of all averted adverse outcomes associated with the disease under study. Because both the numerator and denominator of the ratio are expressed in common units (eg, dollars) and the summary measure is dimensionless, decision makers can compare disparate public health problems and programs. However, it is often difficult to value certain health outcomes in monetary terms (eg, freedom from pain) and it may be distasteful or controversial to value health or a human life in monetary terms.^{3,6}

Regardless of economic evaluation method, the viewpoint from which the analysis is conducted has important implications in the design of an economic study and on the results of the analysis.^{3,4} The study perspective used is particularly important because the costs associated with adverse health, as well as the costs and benefits associated with implementing an intervention aimed at addressing the health issue, are typically not distributed equally among various groups within society. For example, low-income households suffer a disproportionate share of illness because of substandard housing.^{10,11} However, by choosing an appropriate perspective (eg, societal) for the conduct of an

TABLE 1 • Categories of Costs Typically Used by Study Type and Perspective

Example Costs	Study Type					Study Perspective			
	COI	CA	CEA	CUA	CBA	Societal	Government	Insurer/Payer	Individual
Direct medical	X	X ^a	X	X	X	X	X	X	X
Office visits									
Hospitalizations									
Emergency department visit									
Diagnostic tests									
Medical supplies									
Prescription drugs									
Direct nonmedical	X	X ^a	X		X	X			X
Transportation to and from medical services									
Childcare									
Time spent by patient seeking medical care									
Public awareness campaign									
Caregiver time									
Productivity (also known as indirect)	X	X ^a	X		X	X			X
Patient's lost wages due to work or school absence									
Caregiver's lost wages due to work or school absence									
Lost wages due to premature death									
Change in productivity due to morbidity									
Forgone leisure time									
Intangible (quality of life)					X	X			X
Pain and suffering									
Peace of mind									
Social stigmatization									

Abbreviations: CA, cost analysis; CBA, cost-benefit analysis; CEA, cost-effectiveness analysis; COI, cost of illness; CUA, cost-utility analysis.

^aWhen conducted to estimate net costs.

economic evaluation of an intervention aimed at improving low-income housing, all relevant costs and benefits associated with the intervention can be accounted for regardless of who pays or who benefits. Other possible analysis perspectives include the federal, state, or local government; the health insurer or payer (eg, a health maintenance organization or Medicaid); the employer; or the individual. However, the societal perspective is often used in public health and is recommended by the Panel on Cost-effectiveness in Health and Medicine.⁷ The Panel on Cost-effectiveness in Health and Medicine, a 13-member group of non-government scientists and scholars with expertise in CEA, was convened in 1993 by the US Public Health Service to assess how CEAs are being conducted in the field and to make recommendations on how such studies can be conducted to improve their quality and facilitate their comparability. In the societal perspective, all significant costs and health effects associated with everyone affected by the intervention are included in the analysis regardless of who pays or who benefits.^{3,7} However, public health practitioners working at the local level may not have sufficient expertise to use analy-

ses conducted from a societal perspective. In addition, analyses conducted from a societal perspective typically do not value intangibles important to public health practitioners such as social justice.^{1,2} Although economic evaluation from other perspectives often can be deduced from a societal perspective by including only the appropriate subset of costs and consequences in the analysis, such studies may not include all costs of interest to local public health officials (eg, all implementation costs). Consequently, health economists may serve local and state public health agencies by conducting analyses from a government or other payer perspective. Table 1 provides a list of cost categories and examples of the types of data typically used for different study perspectives. Other issues important to conducting and understanding economic analyses, such as study time frame, analytic horizon (eg, the upfront costs of a housing intervention might result in health benefits that can be captured only years later), and discount rates, are not discussed in this article. Others have provided brief overviews of these important economic concepts.^{2,6} In addition, other resources are available for more in-depth study.^{3,5,7}

● Published Costs of Specific Housing-Related Health Outcomes and Interventions

Some housing-related health outcomes and relevant interventions have received considerable attention in health economics, whereas others have not. For example, a search of PubMed and the Internet reveals a substantial body of literature on the cost of asthma morbidity. However, a similar search resulted in no COI studies on CO poisoning. For the current discussion, we include economic analyses on common housing interventions to prevent asthma, lead and CO poisoning, and lung cancer related to radon. All monetary values have been adjusted to 2008 dollars, using the overall Consumer Price Index, which may result in an underestimation of medical costs.¹²

Asthma and indoor agents

Asthma-related costs, estimated at \$20 billion in 2007,¹³ rank among the highest for chronic diseases.¹⁴ On average, each child and adult with asthma costs respectively \$1044 and \$2157 more in direct medical costs than children and adults without asthma¹⁵ and asthmatic children miss 2.5 more days of school a year.¹⁶ Productivity losses due to missed work by parents of children with asthma total \$333 each year per child with asthma, and \$123 of lifetime earnings per school-aged child with asthma is lost because of premature death. Annual mean health care expenditures for children with asthma are nearly 2.5 times the amount incurred for children without asthma (\$2140 vs \$887).¹⁷

Environmental exposures account for a substantial portion of the economic costs of asthma. For example, 1 investigation suggests approximately 20% of asthma cases may be attributable to dampness and mold at an annual cost of \$4.0 billion.¹⁸ More than \$1.1 billion annually in asthma-related direct and indirect costs are estimated to be attributable solely to residential exposures in children and adolescents 16 years or younger.¹⁹

Several COI studies have been conducted for asthma, and CA and CEA have been performed on asthma-related housing interventions (Table 2).^{16,18,20-28} The COI studies were conducted mostly from a societal perspective. One team of researchers limited their study to asthma-related costs for Medicaid recipients and therefore used a payer perspective.²³ Studies vary in the comprehensiveness of cost categories included. For example, medication costs associated with allergic rhinitis, a common comorbidity of asthma, were included in 1 study,²² whereas other studies either did not explicitly state the types of medications considered¹⁶ or included only estimates of costs for asthma-specific

medications.²² Differences in how the study is framed should be considered when comparing study results.⁵

Asthma-related interventions have been the focus of many health economic studies, but few included a housing-modification component.⁸ Of 2 studies that did include such a component, the costs included in each analysis differed substantially. For example, the CA conducted by Krieger et al²⁴ compared only *urgent* direct medical care costs of 2 groups that received different levels (“high intensity” vs “low intensity”) of an home-based environmental intervention, whereas Kattan et al²⁵ were more inclusive in the direct medical costs (eg, both scheduled and unscheduled medical visits, and controller and rescue medications) considered in their CEA.

Two cost analyses suggest that while integrated pest management (IPM), a strategy for reducing exposures to both pesticides and allergens (eg, insects and rodents),^{29,30} is more effective than standard pest management strategies, IPM is initially 2 to 3 times more costly than standard pest management.^{27,28} Because both studies were conducted from the payer perspective, the true total costs of pest control methods studied may not have been adequately quantified (eg, resources used by occupants to purchase and apply supplemental pesticides were not included). In addition, the links between exposures to pesticides in residential settings and health outcomes and associated costs were not examined in either study.

Lead poisoning

Blood lead levels in children in the United States have decreased significantly over the past decade.³¹ The resources essential to achieve this success were allocated, in part, as a result of policy changes made on the basis of published estimates of the financial benefits of eliminating lead exposures.³²⁻³⁷ Although studies demonstrate that blood lead levels have had a staggering impact in terms of productivity losses alone, they focused primarily on intelligence quotient-related productivity improvement. For example, elevated blood lead levels have been linked to many long-term adverse outcomes, including attention-deficit/hyperactivity disorder, juvenile delinquency, and criminal behavior, and an increased need for special education.^{35,38,39} However, these studies did not consider how reducing or eliminating lead exposures in young children could lead to reductions in costs associated with the aforementioned conditions. Thus, the total benefits of lead hazard prevention and mitigation likely are much higher than the estimates reported in studies that focused on productivity losses alone.

A recent CBA that compared the benefits of lead hazard mitigation with costs associated with lead paint

TABLE 2 • Selected Characteristics and Findings of Economic Studies on Asthma

Author, Health Issue, Comparators (Where Applicable)	Model Type, Study Perspective(s), and Population Description	Costs and Benefits Considered	Results
Wang et al ¹⁶ Asthma	COI Societal US children with asthma aged 5-17 y	<i>Direct medical:</i> PHY, UM, ED, IH, OH, and PMED <i>Productivity (indirect):</i> LPRD, LPRD, and LSAD	Total annual costs of asthma = \$2.3 billion (\$926 per child) Total direct costs due to asthma = \$1.2 billion (\$469 per child) Total indirect costs due to asthma = \$1.2 billion (\$456 per child)
Mudarri and Fisk ¹⁸ Asthma	COI Societal National estimate for US children and adults with asthma	<i>Note.</i> Based on previous work by Weiss and Sullivan ²⁰ and Smith et al ²⁰ <i>Direct medical:</i> IH, ED, OH, IP, PHY, and PMED <i>Productivity (indirect):</i> LSAD, LWW, LPHW, LPRD, LPAR, and LRA	Number of asthma cases attributable to dampness and mold = 4.6 million (21% of all cases of asthma) Total annual asthma cost attributable to dampness and mold in homes = \$4.0 billion
Smith et al ²¹ Asthma	COI Societal (presumed, not stated) National estimate for US adults and children with asthma	<i>Direct medical:</i> OPMED, PHY, OH, and ED <i>Productivity (indirect):</i> LPHW, LWW, LSAD, LPAR, and LRA	Total annual costs of asthma = \$8.5 billion; Annual cost per high-cost patient with asthma = \$3754 Annual cost per low-cost patient with asthma = \$203
Cisternas et al ²² Asthma	COI Societal 401 adults with asthma aged 18-50 y	<i>Direct medical:</i> IH, AMV, ED, OH, PMED, and OCMED <i>Direct nonmedical:</i> TRANS, ACP, HWK, and ACRHR <i>Productivity (indirect):</i> LWW and LPHW	Total mean annual asthma-related costs per adult = \$6488 Total mean annual asthma-related costs per adult by asthma severity: Mild = \$3495 Moderate = \$5984 Severe = \$16 924
Piccoro et al ²³ Asthma	COI Payer 24 365 Medicaid recipients with asthma	<i>Direct medical:</i> PMED, MS, ED, IH, OH, etc	Total state (Kentucky) asthma-related costs = \$20.6 million (\$845 per person)
Krieger et al ²⁴ Asthma High-intensity intervention ^b vs low-intensity intervention ^c	CA Perspective not stated 274 low-income children with persistent asthma aged 4-12 y	<i>Direct medical:</i> IH, UM, and ED <i>Intervention:</i> SAL, BEN, SUP, FR, TRAV, OE, and IC	Marginal cost of high-intensity intervention relative to low-intensity intervention = \$151 000 (\$1366 per child) Projected range of 4-y net savings per child among high-intensity intervention relative to low-intensity intervention = \$230-\$877
Kattan et al ²⁵ Asthma Targeted home-based environmental modification vs usual care	CEA Payer 800 children with asthma aged 5-11 y	<i>Direct medical:</i> PHY, UM, ED, IH, and PMED <i>Intervention:</i> SAL, TRAV, PEST, AST, and EQUIP	ICER = \$34 per symptom-free day gained

(continues)

TABLE 2 ● Selected Characteristics and Findings of Economic Studies on Asthma (Continued)

Author, Health Issue, Comparators (Where Applicable)	Model Type, Study Perspective(s), and Population Description	Costs and Benefits Considered	Results
Sullivan et al ²⁶ Asthma	CEA Payer 1033 children with asthma aged 5-11 y	<i>Direct medical:</i> PHY, UM, ED, IH (ICU and non-ICU), and IP <i>Intervention:</i> SAL, BEN, SUP, INTM, TRG, and FR (Note. Intervention costs were included with direct medical costs)	ICER = \$13 per symptom-free day gained
Wang and Bennett ²⁷ IPM IPM vs bait treatment only	CA Payer 12 buildings, 66 apartments in multifamily public housing	<i>Intervention:</i> L and PCM	IPM median cost per apartment = \$74 (>29 wk); Bait treatment cost per apartment = \$40 (>29 wk)
Miller and Meek ²⁸ IPM IPM vs monthly spray or dust treatment	CA Payer IPM—10 buildings, 50 apartments in multifamily public housing Traditional—12 buildings, 50 apartments in multifamily public housing	<i>Intervention:</i> L and PCM	Average cost per unit per treatment for IPM = \$5.51 Average cost per unit per treatment for traditional pest management = \$1.80

Abbreviations: ACP, asthma control products; ACRHR, asthma control-related home repairs; AMV, ambulatory visits; AST, allergy skin tests; BEN, benefits; CA, cost analysis; CEA, cost-effectiveness analysis; COI, cost of illness; ED, emergency department visit; EQUIP, equipment; FR, facility rental; HWK, housework; IC, indirect charges; ICER, incremental cost-effectiveness ratio; IH, inpatient hospital; INTM, intervention-related materials/aids; IP, inpatient physician; IPM, integrated pest management; L, labor; LPAR, parent's/caregiver's loss of productivity; LPHW, loss productivity for those who did not work outside the home; LPRD, loss due to premature death; LRA, loss due to restricted activity; LSAD, loss due to school absence days; LWW, lost work wages; MS, medical services; OCMED, over-the-counter medications; OE, office expenses; OH, outpatient hospital; PCM, pest control materials/equipment; PEST, pest management/treatment; PHY, scheduled medical/physician/office-based visits; PMED, prescription medications; SAL, salaries; SUP, supplies; TRANS, transportation; TRAV, travel; TRG, training; UM, unscheduled medical.

^aHigh-intensity intervention, structured home environmental assessment and resources for reducing environmental exposures.

^bLow-intensity intervention, environmental assessment and bedding encasements.

hazards in homes estimated that exposures due to these hazards costs the US society from \$205 to \$288 billion for a cohort of children 6 years and younger.¹² In one of the few CBAs that explicitly described the intervention being evaluated (lead-safe window replacement),⁴⁰ societal benefits from productivity gains, savings in energy costs, and higher housing market values were all included in the study, but other costs (eg, direct medical costs) and benefits (eg, from reduced crime and special education needs) were not accounted for. In contrast, an earlier CBA included savings resulting from reduced medical and special education costs and expected productivity gains, as well as program costs associated with the intervention.⁴¹

Several of the lead-related evaluations were conducted from a societal perspective.^{12,40,41} However, there are many adverse effects associated with lead exposures that are potentially relevant from a societal perspective that were not included in any of the studies reviewed. For example, none of these studies included costs associated with the effects of in utero lead exposure (eg, reduced gestational age or lower birth

weight) or certain adult adverse outcomes (eg, increases in blood pressure and cardiovascular disease).³⁵

Lung cancer related to radon

Radon is estimated to cause 21 000 lung cancer deaths annually at an average cost of \$1.1 million per person.⁴² In contrast, typical costs for radon mitigation ranges from \$900 to \$2850, with an average per unit cost of \$1350,⁴³ while the cost of making a new radon-resistant home ranges from \$460 to \$660.⁴⁴ There is conflicting evidence on the effectiveness and cost-effectiveness of specific radon prevention and mitigation strategies. For example, basic preventative measures in new homes, such as the use of sealed membranes, have been found to be ineffective in 1 study,⁴⁵ yet highly cost-effective in another study (which implies effectiveness).⁴⁶ In contrast, active radon mitigation in existing housing has been found to be effective^{30,45,47} but may not be cost-effective.⁴⁵ The monetary units here are pounds-sterling, not dollars. When a societal perspective is taken, the determination of whether a

specific radon prevention or mitigation intervention is cost-effective or not rests on many factors. Such factors include, but are not limited to, (1) the action level above which remediation of the home is recommended (currently 4 pCi/L in the United States); (2) the proportion of homes with radon levels over the action level; (3) the proportion of households that have radon levels over the action level that decide to remediate; (4) the risk of developing lung cancer based on radon dose; and (5) the age of the residents living in the home.⁴⁶⁻⁵⁰

Consistent with cost analyses on other health conditions discussed in this article, economic studies on the effectiveness of radon exposure control to improve health tend to undervalue the benefits of the interventions. Three of the 4 CEA studies listed in Table 3 used cost per life-year saved (gained) as a summary measure, thereby facilitating the comparability of study findings.^{13,40,41,46-49,51-53} Although each of these studies accounted for reduced costs attributable to preventing premature death caused by lung cancer, health care costs due to extended life expectancy are generally not considered.⁴⁶ As noted by a team of researchers,⁴⁹ their study (as well as the other studies reviewed for this article) did not include potential benefits such as delayed lung cancer onset, prevention of nonfatal lung cancer, and benefits to future generations that live in high-risk areas where radon prevention or remediation strategies have been implemented (assuming remediation is effective). Of the radon studies reviewed, only 1 was a CUA.⁴⁶

Carbon monoxide poisoning not related to fires

Carbon monoxide is the leading cause of all unintentional poisoning-related deaths in the United States,⁵⁴ especially among adults older than 65 years.⁵³ In residential settings, CO accounts for 5% of poisoning deaths not related to a fire.⁵⁶ While the public health burden of most CO poisoning is small when compared with other housing-related adverse health outcomes, the Centers for Disease Control and Prevention reports non-fire-related CO exposures caused an average of 480 deaths from 2001 to 2002 and more than 15 000 emergency department visits between 2001 and 2003.⁵⁵ More than 50% of CO poisoning incidents reportedly occur in the home.^{57,58} On the basis of a published estimate of the average societal costs of unintentional death in the home⁵⁹ and assuming 50% of deaths occurred in the home,^{58,60} residential CO poisoning-related fatalities costs the US society more than \$500 million annually. Similarly, assuming the average cost for nonfatal injuries is \$17 250,⁵⁹ and 70% of nonfatal CO poisoning incidents occur in the home,⁶¹ morbidity due to residential CO exposures costs approximately \$180 million annually in the United States.

Few published studies on societal costs associated with CO morbidity or mortality were identified. This may be because CO poisoning is difficult to accurately diagnose clinically.^{55,62,63} Although CO detectors are purported to reduce CO poisoning incidents and deaths,⁶⁴ only 1 study on the effectiveness and costs and benefits of these devices was identified.⁵³ This CBA demonstrated that installing CO detectors is not sufficiently beneficial to justify the costs in homes with new gas and liquefied petroleum gas appliances in the UK, since these appliances already have a secondary safety system built-in.

The lack of CE studies on CO detectors is surprising, given the number of published economic studies on smoke alarm, a similar low-cost, early-warning intervention.

● Conclusions

Published economic evaluations for housing-related health outcomes, including asthma, lead poisoning, and radon-related lung cancer, provide valuable information to guide prevention efforts. Nonetheless, more research focusing on the costs of effective housing-related interventions and the resulting economic impact of these interventions is needed. In addition, formal study is needed to demonstrate the effectiveness of interventions for which only anecdotal arguments have been presented. The resulting information can be used to make more efficient use of limited resources, as well as develop and implement programs that will have greater health impact.

Understanding both the strengths and limitations of economic evaluations will help decision makers interpret findings appropriately. For example, a number of economic evaluations reviewed were conducted from the payer perspective. Such studies may be of particular interest to local public health agencies; however, policy makers at the state and federal levels often take a broader view of cost and consequences. Results from CUA and CBA studies enable policy makers at the highest level (eg, Congress, heads of state health departments) to compare disparate health outcomes and related interventions. More CUA and CBA studies are needed to help policy makers who are responsible for allocating resources aimed at addressing wide-ranging problems.

Because decision makers and practitioners in public health increasingly embrace economic analyses to make informed decisions about how best to allocate limited resources, particular attention should be given to important concepts highlighted in this article. These concepts include (1) the selection of the appropriate analytic method(s) to address the question(s) of interest;

TABLE 3 ● Selected Characteristics and Findings of Economic Studies on Indoor Chemical-Related Health Issues

Author, Health Issue, Comparators (Where Applicable)	Model Type, Study Perspective(s), and Population Description	Costs and Benefits Considered	Results
Stefanak et al ⁵¹ Lead poisoning	COI Local government 279 children with lead poisoning	<i>Direct medical:</i> LS, TRMT, FUP, repeat blood testing, EI, SE, and juvenile delinquency	Total annual costs to screen and treat children for lead poisoning = \$597 779 for 279 children
Gould ¹² Lead poisoning Lead paint hazard screening and control vs no action	CBA Societal National cohort of US children 6 y or younger	<i>Direct medical:</i> LS, TRMT, and attention-deficit/hyperactivity disorder <i>Nonmedical direct:</i> Criminal activity, loss tax revenue, and SE <i>Productivity (indirect):</i> LLE <i>Intervention:</i> Unspecified lead hazard control treatment	Total net benefit of lead hazard control: \$193-\$287 billion Cost-benefit ratio = \$18-\$236 for each dollar invested
Nevin et al ⁴⁰ Lead poisoning Lead-safe WR vs no action	CBA Societal Pre-1978 US housing with children aged 6-30 mo	<i>Productivity (indirect):</i> Lifetime earnings, increased market value, and energy savings <i>Intervention:</i> WR ^a	Range of net benefit per housing unit by housing age: Pre-1940 = \$4950-\$6206; 1940-1959 = \$541-\$1796 Total net benefits of lead-safe WR in all pre-1960 housing = \$73.9 billion
Brown ⁴¹ Lead poisoning Strict enforcement of lead poisoning prevention housing policies vs limited enforcement	CBA Societal Strict enforcement: 22 children with lead poisoning living in 22 buildings Limited enforcement: 167 children living in 77 buildings	<i>Direct medical:</i> TRMT, FUP <i>Nonmedical direct:</i> SE, EI, and relocation <i>Productivity (indirect):</i> LLE <i>Intervention:</i> Unspecified lead hazard abatement	Net lifetime cost savings for recurrent cases of elevated lead levels in the blood in the same building in a 10-y period = \$55 145
Gray et al ⁴⁶ Lung cancer Pre and post intervention radon levels in new and existing homes	CEA Societal, NHS, HPA, government, and homeowners Representative national sample of homes	<i>Unspecified lung cancer treatment costs, NHS costs due to added life expectancy, unspecified measures comprising QALY^b</i> <i>Intervention:</i> New homes—Basic preventative measures Existing homes—Identification of existing homes targeted by policy, capital, maintenance, running, and replacement costs of remedial work; lung cancer treatment costs, and health care costs during any extended life expectancy	<i>Preventative measures in new houses:</i> Cost per life year gained (societal) = \$12 075 Cost per QALY (societal) = \$15 424 Cost per QALY (NHS) = \$9216 Cost per QALY (homeowner, HPA, and government) = \$6208 <i>Remediation in existing houses:</i> Cost per life year gained (societal) = \$55 918 Cost per QALY (societal) = \$71 426 Cost per QALY (NHS) = \$9216 Cost per QALY (homeowner, HPA, and government) = \$62 210

(continues)

TABLE 3 • Selected Characteristics and Findings of Economic Studies on Indoor Chemical-Related Health Issues (Continued)

Author, Health Issue, Comparators (Where Applicable)	Model Type, Study Perspective(s), and Population Description	Costs and Benefits Considered	Results
Coskeran et al ⁴⁷ Lung cancer Preremediation radon levels vs postremediation radon levels	Trial and model-based CEA Payer Residents of 77 remediated houses in 5 areas	Unspecified costs associated with lung cancer (based on work by Colgan and Gutierrez ⁴⁸) ^b <i>Intervention:</i> Radon testing and remediation program costs, initial measurement; remediation work (sump), retesting; fan replacement every 10 y	Range of annualized cost per lung cancer saved = \$383 036-\$1 855 135 Range of cost per life-years gained = \$25 698-\$129 223
Ford et al ⁴⁹ Lung cancer Various screening strategies (universal, targeted, modified universal, and modified targeted) vs no action	CEA Societal Universal: 250 million people living in 100.5 million homes Targeted: 71 million people living in 25.9 million homes	<i>Direct medical:</i> Unspecified costs due to lung cancer-related morbidity and mortality <i>Productivity (indirect):</i> Unspecified losses due to lung cancer-related morbidity and mortality <i>Intervention:</i> Program, testing, mitigation	Cost per life-year saved by screening strategy (at 4-pCi/L radon action threshold): Universal = \$620 000 Targeted = \$492 000 Modified universal = \$194 000 Modified target = \$119 000
Coskeran et al ⁵² Lung cancer Premitigation program radon levels vs postmitigation program radon levels	CEA Payer 176 people residing in 173 radon-remediated houses	Unspecified costs associated with lung cancer ^b <i>Intervention:</i> Initial measurement, remediation work, retesting	Annualized cost per lung cancer avoided (assuming 6% discount rate and 40-y accounting period) = \$184 997 Range of cost-benefit ratios (scenario dependent) = 0.02-0.28
UK Department of Communities and Local Governments ⁵³ CO poisoning CO detector vs no detector	Societal 22 million domestic properties in Great Britain	Unspecified costs associated with CO poisoning-related deaths and injuries prevented <i>Intervention:</i> Average installation and maintenance costs for sealed battery CO detector	

Abbreviations: CBA, cost-benefit analysis; CEA, cost-effectiveness analysis; CO, carbon monoxide; COI, cost of illness; EI, environmental investigation; FUP, follow-up; HPA, Health Protection Agency; LLE, loss lifetime earnings; LS, lead screening; NHS, National Health System; QALY, quality-adjusted life years; SE, special education; TRMT, treatment; WR, window replacement.

^aWindow replacement include replacement of all single-pane windows with high efficiency Energy Star windows, paint stabilization, specialized cleaning, and clearance testing.

^bNonintervention-related costs were generally not described or not described in sufficient detail to accurately categorize as direct, nonmedical, and/or productivity.

(2) the perspective from which the analysis is conducted; (3) the comprehensiveness of important costs and consequences (both benefits and unintended negative outcomes) included in the analysis; and (4) the potential impact of omitted costs and benefits.

REFERENCES

1. Neumann PJ, Jacobson PD, Palmer JA. Measuring the value of public health systems: the disconnect between health economists and public health practitioners. *Am J Public Health*. 2008;98(12):2173-2180.
2. Grosse SD, Teutsch SM, Haddix AC. Lessons from cost-effectiveness research for United States Public Health Policy. *Annu Rev Public Health*. 2007;28:365-391.
3. Haddix AC, Teutsch SM, Corso PS. *Prevention Effectiveness: A Guide to Decision Analysis and Economic Evaluation*. New York, NY: Oxford University Press; 2002.
4. Zaza S, Briss PA, Harris K, eds. *The Guide to Community Preventive Services: What Works to Promote Health?* Task Force on Community Health Services. New York, NY: Oxford University Press; 2005.

5. Drummond MF, Sculpher MJ, Torrance GW, O'Brien BJ. *Methods for the Economic Evaluation of Health Care Programmes*. 3rd ed. New York, NY: Oxford University Press; 2005.
6. Miller TR, Levy DT. Cost outcome analysis in injury prevention and control: a primer on methods. *Inj Prev*. 1997;3(4):288-293.
7. Gold MR, Siegel JE, Russell LB, Weinstein MC. *Cost-effectiveness in health and medicine*. New York, NY: Oxford University Press; 1996.
8. Campbell JD, Spackman DE, Sullivan SD. Health economics of asthma: assessing the value of asthma interventions. *Allergy*. 2008;63(12):1581-1592.
9. Gold MR, Stevenson D, Fryback DG. HALYS and QALYS and DALYS, Oh My: similarities and differences in summary measures of population health. *Annu Rev Public Health*. 2002;23:115-134.
10. Krieger J, Higgins DL. Housing and health: time again for public health action. *Am J Public Health*. 2002;92(5):758-768.
11. Matte TD, Jacobs DE. Housing and health—current issues and implications for research and programs. *J Urban Health*. 2000;77(1):7-25.
12. Gould E. Childhood lead poisoning: conservative estimates of the social and economic benefits of lead hazard control. *Environ Health Perspect*. 2009;117(7):1162-1167.
13. National Institutes of Health/National Heart Lung, and Blood Institute. Morbidity and mortality: 2007 chart book on cardiovascular, lung, and blood diseases. <http://www.nhlbi.nih.gov/resources/docs/07-chtbk.pdf>. accessed January 27, 2010.
14. Bahadori K, Doyle-Waters MM, Marra C, et al. Economic burden of asthma: a systematic review. *BMC Pulm Med*. 2009;9:24.
15. Kamble S, Bharmal M. Incremental direct expenditures of treating asthma in the United States. *J Asthma*. 2009;46(1):73-80.
16. Wang LY, Zhong Y, Wheeler L. Direct and indirect costs of asthma in school-age children. *Prev Chronic Dis*. 2005;2(1):A11.
17. Lozano P, Sullivan SD, Smith DH, Weiss KB. The economic burden of asthma in US children: estimates from the National Medical Expenditure Survey. *J Allergy Clin Immunol*. 1999;104(5):957-963.
18. Mudarri D, Fisk WJ. Public health and economic impact of dampness and mold. *Indoor Air*. 2007;17(3):226-235.
19. Lanphear BP, Kahn RS, Berger O, Auinger P, Bortnick SM, Nahhas RW. Contribution of residential exposures to asthma in U.S. children and adolescents. *Pediatrics*. 2001;107(6):E98.
20. Weiss KB, Sullivan SD. The health economics of asthma and rhinitis. I. Assessing the economics impact. *J Allergy Clin Immunol*. 2001;107(1):3-8.
21. Smith DH, Malone DC, Lawson KA, Okamoto LJ, Battista C, Saunders WB. A national estimate of the economic costs of asthma. *Am J Respir Crit Care Med*. 1997;156(3, pt 1):787-793.
22. Cisternas MG, Blanc PD, Yen IH, et al. A comprehensive study of the direct and indirect costs of adult asthma. *J Allergy Clin Immunol*. 2003;111(6):1212-1218.
23. Piccoro LT, Potoski M, Talbert JC, Doherty DE. Asthma prevalence, cost, and adherence with expert guidelines on the utilization of health care services and costs in a state Medicaid population. *Health Serv Res*. 2001;36(2):357-371.
24. Krieger JW, Takaro TK, Song L, Weaver M. The Seattle-King County Healthy Homes Project: a randomized, controlled trial of a community health worker intervention to decrease exposure to indoor asthma triggers. *Am J Public Health*. 2005;95(4):652-659.
25. Kattan M, Stearns SC, Crain EF, et al. Cost-effectiveness of a home-based environmental intervention for inner-city children with asthma. *J Allergy Clin Immunol*. 2005;116(5):1058-1063.
26. Sullivan SD, Weiss KB, Lynn H, et al. The cost-effectiveness of an inner-city asthma intervention for children. *J Allergy Clin Immunol*. 2002;110(4):576-581.
27. Wang C, Bennett GW. Comparative study of integrated pest management and baiting for German cockroach management in public housing. *J Econ Entomol*. 2006;99(3):879-885.
28. Miller DM, Meek F. Cost and efficacy comparison of integrated pest management strategies with monthly spray insecticide applications for German cockroach (Diptera: Blattellidae) control in public housing. *J Econ Entomol*. 2004;97(2):559-569.
29. Kass D, McKelvey W, Carlton E, et al. Effectiveness of an integrated pest management intervention in controlling cockroaches, mice, and allergens in New York City public housing. *Environ Health Perspect*. 2009;117(8):1219-1225.
30. National Center for Healthy Housing. Housing interventions and health: a review of the evidence. <http://www.nchh.org/LinkClick.aspx?fileticket=2lvaEDNBIdU%3d&tabid=229>. Accessed January 27, 2010.
31. Jones RL, Homa DM, Meyer PA, et al. Trends in blood lead levels and blood lead testing among US children aged 1 to 5 years, 1988-2004. *Pediatrics*. 2009;123(3):e376-e385.
32. Jacobs DE, Kelly T, Sobolewski J. Linking public health, housing, and indoor environmental policy: successes and challenges at local and federal agencies in the United States. *Environ Health Perspect*. 2007;115(6):976-982.
33. Landrigan PJ, Schechter CB, Lipton JM, Fahs MC, Schwartz J. Environmental pollutants and disease in American children: estimates of morbidity, mortality, and costs for lead poisoning, asthma, cancer, and developmental disabilities. *Environ Health Perspect*. 2002;110(7):721-728.
34. Salkever DS. Updated estimates of earnings benefits from reduced exposure of children to environmental lead. *Environ Res*. 1995;70(1):1-6.
35. Schwartz J. Societal benefits of reducing lead exposure. *Environ Res*. 1994;66(1):105-124.
36. Grosse SD, Matte TD, Schwartz J, Jackson RJ. Economic gains resulting from the reduction in children's exposure to lead in the United States. *Environ Health Perspect*. 2002;110(6):563-569.
37. US Department of Housing and Urban Development. Economic analysis of the final rule on lead-based paint: requirements for notification, evaluation, and reduction of lead-based paint hazards in federally-owned residential property and housing receiving federal assistance. <http://www.hud.gov/offices/lead/library/enforcement/completeRIA1012.pdf>. Accessed April 6, 2010.
38. Braun JM, Kahn RS, Froehlich T, Auinger P, Lanphear BP. Exposures to environmental toxicants and attention deficit

- hyperactivity disorder in U.S. children. *Environ Health Perspect*. 2006;114(12):1904-1909.
39. Bellinger DC. Neurological and behavioral consequences of childhood lead exposure. *PLoS Med*. 2008;5(5):e115.
 40. Nevin R, Jacobs DE, Berg M, Cohen J. Monetary benefits of preventing childhood lead poisoning with lead-safe window replacement. *Environ Res*. 2008;106(3):410-419.
 41. Brown MJ. Costs and benefits of enforcing housing policies to prevent childhood lead poisoning. *Med Decis Making*. 2002;22(6):482-492.
 42. US Environmental Protection Agency. Technical support document for the 1992 citizens guide to radon. <http://www.epa.gov/radon/pubs/#index6>. Accessed August 24, 2009.
 43. US Environmental Protection Agency. Consumer's guide to radon reduction: how to fix your home. <http://www.epa.gov/radon/pdfs/consguid.pdf>. Accessed September 30, 2009.
 44. US Environmental Protection Agency. Buying a new home: how to protect your family from radon. www.epa.gov/radon/pubs/rrnc-tri.html. Accessed September 30, 2009.
 45. Groves-Kirkby CJ, Denman AR, Phillips PS, Crockett RG, Woolridge AC, Tornberg R. Radon mitigation in domestic properties and its health implications—a comparison between during-construction and post-construction radon reduction. *Environ Int*. 2006;32(4):435-443.
 46. Gray A, Read S, McGale P, Darby S. Lung cancer deaths from indoor radon and the cost effectiveness and potential of policies to reduce them. *BMJ*. 2009;338:a3110. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=19129153. Accessed January 27, 2010.
 47. Coskeran T, Denman AR, Phillips PS, Gillmore GK. A critical comparison of the cost-effectiveness of domestic radon remediation programmes in three counties of England. *J Environ Radioact*. 2002;62(2):129-144.
 48. Colgan P, Gutierrez J. Cost-effectiveness of reducing radon exposure in Spanish dwellings. *J Radiol Prot*. 1996;16:181-190.
 49. Ford ES, Kelly AE, Teutsch SM, Thacker SB, Garbe PL. Radon and lung cancer: a cost-effectiveness analysis. *Am J Public Health*. 1999;89(3):351-357.
 50. Stigum H, Strand T, Magnus P. Should radon be reduced in homes? A cost-effect analysis. *Health Phys*. 2003;84(2):227-235.
 51. Stefanak M, Diorio J, Frisch L. Cost of child lead poisoning to taxpayers in Mahoning County, Ohio. *Public Health Rep*. 2005;120(3):311-315.
 52. Coskeran T, Denman A, Phillips P. The costs of radon mitigation in domestic properties. *Health Policy*. 2001;57(2):97-109.
 53. UK Department of Communities and Local Governments. Study on the provision of CO detectors under the building regulations (BD2754). <http://www.communities.gov.uk/publications/planningandbuilding/studycarbonmonoxide-detectors>. Accessed January 27, 2010.
 54. US Environmental Protection Agency. Preventing carbon monoxide poisoning: information for older adults and their caregivers. <http://www.epa.gov/aging/resources/factsheets/pcmp/index.htm>. Accessed January 27, 2010.
 55. Centers for Disease Control and Prevention. Unintentional non-fire-related carbon monoxide exposures—United States, 2001-2003. *MMWR Morb Mortal Wkly Rep*. 2005;54(02):36-39.
 56. Runyan CW, Casteel C, eds. *The State of Home Safety in America: Facts About Unintentional Injuries in the Home*. 2nd ed. Washington, DC: Home Safety Council; 2004.
 57. Carlson SA. *Non-Fire Carbon Monoxide Deaths Associated With the Use of Consumer Products 2001 Annual Estimates*. Bethesda, MD: Consumer Product Safety Commission. <http://www.cpsc.gov/LIBRARY/co04.pdf>. Accessed January 27, 2010.
 58. Scheerer A, Struttman T. Carbon monoxide poisoning in Kentucky. *J Ky Med Assoc*. 2002;100(10):447-453.
 59. Zaloshnja E, Miller TR, Lawrence BA, Romano E. The costs of unintentional home injuries. *Am J Prev Med*. 2005;28(1):88-94.
 60. Ashley P, Anderson J, Menkedick JR, Wooton MA. Healthy homes issues: carbon monoxide. <http://www.healthyhomes-training.org/Documents/HUD/HUD.CO-Brief.pdf>. Accessed January 27, 2010.
 61. Centers for Disease Control and Prevention. Nonfatal, unintentional, non-fire-related carbon monoxide exposures—United States, 2004-2006. *MMWR Morb Mortal Wkly Rep*. 2008;57(33):896-899.
 62. Raub JA, Mathieu-Nolf M, Hampson NB, Thom SR. Carbon monoxide poisoning—a public health perspective. *Toxicology*. 2000;145(1):1-14.
 63. Prockop LD, Chichkova RI. Carbon monoxide intoxication: an updated review. *J Neurol Sci*. 2007;262(1-2):122-130.
 64. Yoon SS, Macdonald SC, Parrish RG. Deaths from unintentional carbon monoxide poisoning and potential for prevention with carbon monoxide detectors. *JAMA*. 1998;279(9):685-687.