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Economic Burden of Occupational Injury and Illness in the United States

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Context: The allocation of scarce health care resources requires a knowledge of disease costs. Whereas many studies of a variety of diseases are available, few focus on job-related injuries and illnesses. This article provides estimates of the national costs of occupational injury and illness among civilians in the United States for 2007.

Methods: This study provides estimates of both the incidence of fatal and nonfatal injuries and nonfatal illnesses and the prevalence of fatal diseases as well as both medical and indirect (productivity) costs. To generate the estimates, I combined primary and secondary data sources with parameters from the literature and model assumptions. My primary sources were injury, disease, employment, and inflation data from the U.S. Bureau of Labor Statistics (BLS) and the Centers for Disease Control and Prevention (CDC) as well as costs data from the National Council on Compensation Insurance and the Healthcare Cost and Utilization Project. My secondary sources were the National Academy of Social Insurance, literature estimates of Attributable Fractions (AF) of diseases with occupational components, and national estimates for all health care costs. Critical model assumptions were applied to the underreporting of injuries, wage-replacement rates, and AFs. Total costs were calculated by multiplying the number of cases by the average cost per case. A sensitivity analysis tested for the effects of the most consequential assumptions. Numerous improvements over earlier studies included reliance on BLS data for government workers and ten specific cancer sites rather than only one broad cancer category.

Findings: The number of fatal and nonfatal injuries in 2007 was estimated to be more than 5,600 and almost 8,559,000, respectively, at a cost of $6 billion

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and $186 billion. The number of fatal and nonfatal illnesses was estimated at more than 53,000 and nearly 427,000, respectively, with cost estimates of $46 billion and $12 billion. For injuries and diseases combined, medical cost estimates were $67 billion (27% of the total), and indirect costs were almost $183 billion (73%). Injuries comprised 77 percent of the total, and diseases accounted for 23 percent. The total estimated costs were approximately $250 billion, compared with the inflation-adjusted cost of $217 billion for 1992.

Conclusions: The medical and indirect costs of occupational injuries and illnesses are sizable, at least as large as the cost of cancer. Workers' compensation covers less than 25 percent of these costs, so all members of society share the burden. The contributions of job-related injuries and illnesses to the overall cost of medical care and ill health are greater than generally assumed.

Keywords: Cost, job-related injury, national estimate.

Cost estimates are essential to decision makers attempting to wisely allocate scarce health care resources. Cost-of-illness studies for many diseases continue to proliferate (Foster et al. 2006; Petersen and American Diabetes Association 2008; Rosamond et al. 2007, 2008), with cost estimates for coronary heart disease, stroke, cancer, and hypertension updated annually (Rosamond et al. 2007, 2008). By contrast and despite its importance, the generation of information about the costs of occupational injury and illness has not kept pace, as the most recent comprehensive estimate for U.S. costs applies to 1992 (Leigh et al. 1997).

Nevertheless, there are several less than comprehensive and related studies. The National Academy of Social Insurance annually updates its estimates of the costs of workers' compensation (Sengupta, Reno, and Burton 2009). But workers' compensation data are incomplete. Bonauto and colleagues (2010) found that workers' compensation records miss from 23 to 53 percent of all medically attended nonfatal injuries, and Leigh and Robbins (2004) found that workers' compensation missed at least 91 percent of occupational disease deaths. Although Corso and colleagues (2006) generated national estimates for injuries in 2000, they did not separate those that were job related. Biddle (2009) provided cost estimates for occupational injury deaths, but not for nonfatal injuries or diseases. The National Safety Council (NSC 2009) calculates the costs of occupational injuries but excludes assaults, murders, and all illnesses. Finally, the national cost estimates for circulatory disease, cancer, and chronic obstructive pulmonary disease (COPD) do not estimate the portions of these diseases attributed to job-related exposures.

The aim of this study is to estimate the national costs of occupational injuries and illnesses among civilians in 2007. To achieve that aim, I have calculated the numbers and costs of fatal and nonfatal injuries and illnesses. Costs are divided into medical and indirect categories. I use broad methodologies such as the cost of illness, incidence, prevalence, and societal perspective that are standard in studies of nonoccupational diseases and injuries. Numbers and costs for all categories are combined to produce the overall most probable estimate of approximately $250 billion for 2007. Finally, a sensitivity analysis investigates the effects of consequential assumptions.

This study introduces numerous methodological advances over one that I and my colleagues conducted earlier (Leigh et al. 1997). For example, first, the previous study estimated injuries for state and local government employees by extrapolating from private-sector employees, whereas this study uses new U.S. Bureau of Labor Statistics (BLS) data from government employees. Second, the current study estimates those injuries for the self-employed and agricultural workers that are not simply averages of those in all other private-sector workers. Third, I rely on recent epidemiologic evidence for fractions of diseases such as cancer and COPD that are attributable to workplace exposures. Fourth, I use hospital costs per hospital stay rather than simply days in the hospital to estimate medical costs. Additional advances are discussed as well.

These estimates should help inform the debate about the relative costs associated with occupational injuries and illnesses versus other diseases, as well as estimate costs not covered by workers' compensation. These estimates may also inform decisions by occupational safety and health stakeholders regarding the allocation of resources to prevent injuries versus diseases.

Methods and Data

All the numbers reported in this article are estimates generated by applying a set of methodological assumptions to available data. This section on methods and data is divided into nine subsections. The first two describe the cost of illness and the incidence and prevalence methods, and the methods in subsections 3 through 8 pertain to counting and costing for fatal and nonfatal injuries and illnesses. Each of subsections 3 through 8 contains information on data sources. The methodology appendix describes the methodology of these subsections, and the ninth subsection describes the sensitivity analysis.

1. Cost-of-Illness Estimates

For the cost-of-illness estimates, I divided the costs into medical and indirect categories from the societal perspective (Rice, Hodgson, and Kopstein 1985). Medical costs were spending on hospitals, physicians, pharmaceuticals, and nursing homes, and indirect costs were current and future lost earnings, fringe benefits, and home production (e.g., making home repairs, cooking, cleaning, and rearing children). For fatal disease calculations, I divided the indirect costs into morbidity and mortality categories. Morbidity costs were lost earnings, benefits, and home production for persons living with a fatal disease. For injuries and nonfatal illnesses, this study followed the standard practice of simply using "fatal" and "nonfatal" categories. All indirect costs for fatal injuries and diseases were estimated in present-value formulas that used 3 percent discount rates (Leigh et al. 1997).

2. Incidence and Prevalence

Incidence methods count new injuries and illnesses in a given year and estimate the associated current and future costs. Prevalence methods estimate only the costs of injuries and diseases for a given year, even if the injuries or diseases occurred or were diagnosed in previous years. From a business point of view, incidence measures are preferred because investment decisions to improve health (and reduce illness and injury) require estimates of future costs. Accordingly, and following Corso and colleagues' (2006) and Leigh and colleagues' (1997) methods for injuries, this study generated incidence measures of fatal and nonfatal injuries and nonfatal illnesses, as well as the indirect costs of all injuries and diseases. Incidence measures were not estimated for the medical costs of fatal diseases because of data restrictions and because prevalence measures are preferred in the literature on disease medical costs (Foster et al. 2006; Petersen and the American Diabetes Association 2008; Rosamond et al.

2007, 2008). Considerable prevalence data on the numbers of disease deaths and hospital costs are available. By comparison, little information is available on the numbers of newly diagnosed fatal diseases and even less on forecasted future costs. The National Council on Compensation Insurance (NCCI) (2008) publishes data on the current and forecasted costs of new workers' compensation cases for injuries and illnesses combined. More than 92 percent of workers' compensation costs apply to injuries (Leigh and Robbins 2004), and the NCCI does not publish cost data for only disease deaths.

3. Counting and Costing Nonfatal Injuries

The numbers of nonfatal injuries from the private sector and state and local governments were drawn from the U.S. Bureau of Labor Statistics' (BLS) Annual Survey of Occupational Injuries and Illnesses (SOII) (2010a). Data from federal employees came from the federal Office of Workers' Compensation Programs (2010). Neither government data set includes military personnel. Employment data for employees and owners of farms with fewer than eleven employees as well as all other employees who were "out of scope" for the SOII were drawn from the BLS's Quarterly Census of Employment and Wages (2010d). Numbers of nonfarming self-employed persons were derived from the BLS's Current Population Survey (2010b). In addition to adjusting for intentional SOII omissions for farmers, farmworkers, self-employed persons, and "out-of-scope" workers, this study adjusted for underreporting, that is, accidental or willful omissions on Occupational Safety and Health Administration (OSHA) 300 forms, which are the basis of the SOII. I used the most probable rate of 40 percent, which I took from a study using 1999 data (Leigh, Marcin, and Miller 2004). This 40 percent coincided with a 41 percent rate for injuries with no days lost and a 36 percent rate for those with at least one day of work lost. Percentages other than 40 percent are considered in the sensitivity analysis.

Estimates of medical and indemnity cost per injury are from the NCCI (NCCI 2008). I multiplied the SOII-based estimates of numbers of injuries within workers' compensation categories by NCCI-based average medical and indemnity costs estimates to produce the total medical and indemnity costs.

Wage-replacement rates (ratios of workers' compensation benefits to wages) were derived from Boden, Reville, and Biddle (2005); Reville and colleagues (2001); Guo and Burton (2010); and Hunt and colleagues (2004). Fringe benefits and home production are from Grosse (2003); Leigh and colleagues (1997); and Bradley and colleagues (2008). Employers' costs for turnover, hiring, and training replacements were derived from Wang and colleagues (2006). Workers' compensation administrative costs are from ratios of premiums to benefits in NCCI data (NCCI 2008; Sengupta, Reno, and Burton 2009), and nonworkers' compensation administrative costs were derived from estimates of all national medical spending (Hartman et al. 2009; Levit et al. 2004; Smith et al. 2006). The methodology appendix provides additional detail.

4. *Counting and Costing Nonfatal Illnesses*

The numbers of nonfatal illness cases are from the same source as this study used for nonfatal injuries: the SOII, which followed the BLS's classifications for illnesses including dermatitis, poisonings, carpal tunnel syndrome, tendonitis, and hernia. On the one hand, my restriction to the BLS's classifications means that job-related osteoarthritis and depression are ignored (Michie and Williams 2003; Leigh and Robbins 2004). But on the other hand, the BLS's classifications are widely viewed as valid and correspond to workers' compensation illness categories. The same methods for estimating numbers and costs for nonfatal injuries described earlier were applied to nonfatal illnesses.

5. *Counting and Costing Fatal Injuries*

This study used the BLS's 2007 Census of Fatal Occupational Injuries (CFOI) estimate of 5,657, without adjustment (U.S. Bureau of Labor Statistics 2011a). To estimate medical costs, I applied the same method just outlined to temporary injuries. "First report" data are from the NCCI, and weighted averages were constructed with the data for thirty-six to forty-six states and the District of Columbia. For indirect costs, this study began with Biddle's (2009) total estimates per death, which include lost wages, fringe benefits, home production, and medical costs. I subtracted medical costs. Biddle (2009) generated incidence costs using present-value formulas accounting for the probabilities of surviving from one year to the next, age, race, gender, occupation, industry, economic growth rate, and the 3 percent discount rate. I assumed that the same percentages for fringe benefits and home production for nonfatal injuries applied to fatal injuries. The methodology appendix offers more details.

6. *Counting Fatal Diseases*

To estimate the number of deaths from disease, I updated the most recent comprehensive estimates from Steenland and colleagues (2003). First, I identified those diseases for which there was substantial evidence of an occupational risk component. Second, I established age brackets that corresponded to occupational exposures. In most cases, the age brackets were ≧30, with no upper age limit. For coronary heart disease and stroke, however, the brackets differed depending on exposure to job strain, shift work, and noise (ages 20 to 69) or environmental tobacco smoke (ages 35 to 69). For asthma, the bracket was ≧20, with no upper limit. Third, I mapped the ICD-9 codes into ICD-10 codes. Fourth, this study used the CDC's estimates of deaths for the widest variety of diseases within the appropriate ICD-10 codes for 2005, the most recent year available (CDC 2009). Fifth, I used Steenland and colleagues' attributable fractions (AFs) (2003), dividing the upper and lower AF ranges in half and creating a single midpoint estimate for each disease. Finally, I multiplied the AFs by the numbers of deaths for each disease. Additional details are contained in the methodology appendix.

7. *Direct Costs of Fatal Diseases*

This study took a top-down approach. The beginning numbers were drawn from Hartman and colleagues' (2009) estimates of national spending for 2007: $696.5 billion for hospitals, $606.9 billion for professional services excluding dental, $289.3 billion for pharmaceuticals and medical devices, and $190.4 billion for nursing homes. I then multiplied these national figures by the estimates of percentage contributions for specific diseases to all diseases and injuries and also by the AFs. The simplest percentage attributed to a specific disease corresponded to the ratio of hospital charges for that disease within the appropriate age brackets divided by the total charges for all disease and injury hospitalizations for all age brackets in the country. I then multiplied this product by Steenland and colleagues' AF for that disease (2003). The hospital data are from the Healthcare Cost and Utilization Project (HCUP) (AHRQ 2010). Similar methods were applied to each category of spending—professional services, pharmaceuticals, and nursing homes—for which the hospital percentages were used as anchors. When data were available, the latter categories were also adjusted for ratios of inpatient versus outpatient visits that altered the hospital percentage anchors. The reasoning was that some diseases, such as asthma, generated proportionately more inpatient versus outpatient visits than did other diseases, such as COPD. Outpatient data were drawn from HCUP and Schappert and Rechtsteiner (2008). These outpatient adjustment data were available only for asthma, COPD, heart disease, and stroke and were applied to professional services and pharmaceutical costs but not nursing homes. This study assumed that nursing homes were for people with serious conditions that required more intensive care than simple visits to a physician, and therefore the hospital ratio anchor alone—without outpatient adjustment—was appropriate. See the methodology appendix for more details.

8. *Indirect Costs of Fatal Diseases*

This study followed accepted practice by (1) estimating the numbers of disease deaths within age and gender groups; (2) estimating lost wages, fringe benefits, and lost home production (separately) within the same age and gender groups by disease; and (3) multiplying the numbers of deaths by cost per death. Ideally, each person's age of death would be matched to lost wages, fringe benefits, and home production for the same age, but no data were available to make a perfect match. Consequently, I posited four groups—women aged <65, men aged <65, women aged ≧65, and men aged ≧65—for which data were available. Within these four groups, I posited typical ages of death that differed by disease depending on the disease characteristics and the AF age limits. A 3 percent discount rate also was applied (Gold et al. 1996). More details are available in the methodology appendix.

9. *Sensitivity Analysis*

This study relied on many assumptions to generate estimates. I changed the critical values of the most consequential parameters in different scenarios, and I generated alternative total cost estimates in the sensitivity analysis appendix. For example, one alternative scenario changed the underreporting percentage to 20 percent, and another changed it to 60 percent. Two other scenarios increased and decreased the assumed wage-replacement rates. Additional scenarios addressed administrative costs, ranges for estimates of disease deaths (with special consideration of circulatory disease), employers' hiring and training costs, and morbidity costs of fatal diseases.

The sensitivity analysis also contains an estimate of job-related osteoarthritis, a disease that can develop in the knees and hips several years after an occupational injury to those same joints (Aluoch and Wao 2009). Epidemiological estimates of occupational deaths do not include job-related arthritis, however, because it is not fatal and I am not aware of any separate AF estimates by epidemiologists. Because of the delay between an injury and the development of job-related osteoarthritis, the SOII captures very few, if any, cases. Because of these limitations, the estimate for job-related arthritis was included in the sensitivity analysis rather than in the most probable total cost estimate of $250 billion. Additional information about all the scenarios is available in the sensitivity analysis appendix.

Results

Numbers and Costs of Fatal and Nonfatal Injuries

The 2007 BLS-SOII estimate of nonfatal injuries in the private sector, excluding those on crop and livestock farms, was 3,765,600. Before adjusting for underreporting, I estimated 39,913 nonfatal injuries for employees and 31,212 for the self-employed in crop and livestock farms; 919,718 for state and local government employees; 108,399 for the federal government (excluding military) employees; 242,248 for all other self-employed persons; and 19,776 for "out-of-scope" BLS workers such as domestics and railroad workers. These numbers summed to 5,126,866 nonfatal injuries. After adjusting for underreporting, I calculated 8,558,962 nonfatal injuries. If we assume that the BLS counted all state and local government workers' injuries for the twenty-four missing states at the same rate as for the twenty-six included states as well as the 30,800 number that the BLS recorded for crops and livestock, then the BLS would have counted 4,716,118 in total. This study therefore estimated that the BLS missed 44.9 percent of the nonfatal injuries.

Table 1 presents estimates of the numbers and medical costs of nonfatal and fatal injuries. Of the approximately 8.5 million occupational injuries, the vast majority (more than 6 million) did not involve time away from work. For more serious injuries, more than 900,000 workers missed one to four days of work owing to an injury; more than 1,000,000 experienced temporary total disability; more than half a million had an

TABLE 1
Estimated Number and Medical Costs of Nonfatal and Fatal Occupational Injuries, 2007

Category	Number and Percentage (of column) of Injuries	Total Medical Costs (in $billions) and Percentage (of column)	Average Medical Costs per Injury
Nonfatal injuries			
Injuries with no days away from work	6,084,086 (71.0%)	$5.69 (12.3%)	$935
Injuries with 1 to 4 days away from work	934,049 (10.9%)	$0.87 (1.9%)	$935
Temporary total disabilities	1,020,181 (11.9%)	$8.21 (17.7%)	$8,046
Permanent partial disabilities	512,438 (6.0%)	$25.58 (55.3%)	$49,925
Permanent total disabilities	8208 (<0.1%)	$5.59 (12.1%)	$681,615
Total for nonfatal injuries	8,558,962 (99.9%)	$45.95 (99.3%)	$5,369
Fatal injuries	5657 (<0.1%)	$0.31 (0.7%)	$55,595
Total for nonfatal and fatal injuries	8,564,619	$46.26	$5,401

Note: Owing to rounding, columns and rows may not sum.

Sources: Biddle 2009; NCCI 2008; U.S. Bureau of Labor Statistics 2010a, 2010b, 2010c, 2010d, 2011a.

injury that caused a permanent disability (partial in most cases); and 5,657 experienced a fatal injury on the job. The medical costs per case were the highest by far for the 8,200 who were permanently totally disabled by a workplace injury, with the medical costs averaging more than $680,000 per case. Permanent partial disabilities generated the greatest total medical costs, and fatal injuries, the least. The identical estimate of $935 in table 1's top two right-side cells was the result of applying the same assumptions to the medical costs for both cases with no days lost and cases with one to four days lost. The NCCI data on medical costs did not distinguish between these two BLS-SOII categories involving cases that did not qualify for indemnity payments.

Numbers and Costs for Fatal and Nonfatal Diseases

Table 2 shows the numbers of disease-related deaths and their associated medical costs. The three diseases with greatest mortality were, in order, all cancers (combined), COPD, and circulatory disease. The three diseases with greatest medical costs were, in order, circulatory disease, all cancers, and COPD. For several reasons, the ranking of costs does not perfectly mirror the ranking for the numbers of deaths. First, the costs were based on hospitalizations, not deaths. For example, although asthma generated considerable costs, it accounted for only a small percentage of the deaths. Second, circulatory diseases had lower age limits than did either cancer or COPD. Younger persons are more likely than older persons to recover rather than die during hospitalizations. Third, because of this study's age limit of sixty-nine, private insurers paid higher percentages than did Medicare of the cost of circulatory diseases than of cancer, and private insurers pay more than Medicare does for hospital services. Fourth, additional analysis revealed that cancer was more deadly than circulatory disease even within the same age categories. For example, I compared the largest cancer category (lung cancer) with the largest circulatory category (coronary heart disease, CHD) for the largest age category common to both (45 to 65 years). The HCUP data indicated that the percentage of lung cancer patients who died in the hospital was nearly four times greater than the percentage of CHD patients who died in the hospital. For these four reasons, therefore, table 2 does not include an average-costs-per-death column; the numbers of persons generating any medical costs such as hospitalizations, physicians' visits, or pharmaceutical use are not the same as the numbers of deaths. The medical cost data for the deadly diseases include both fatalities and people living with diseases (nonfatalities).

Numbers and Costs for Injuries, Illnesses, and Diseases Combined

Table 3 presents the cost data across medical and indirect categories for both illnesses and injuries. Injuries accounted for almost 77 percent of the approximately $250 billion total. In addition, injuries can be compared with diseases. Medical costs took a larger share of the total costs of disease than of injury, and most of the costs associated with

TABLE 2
Estimated Number of Disease Deaths, Nonfatal Cases, and Medical Costs, 2007

Disease and Subcategories	Number of Deaths and Cases Percentage (of column) for Deaths Only	Medical Costs ($billions) Percentage (of column) for Deaths Only
Fatal diseases		
Respiratory diseases		
Pneumoconiosis	985 (1.8%)	$0.05 (0.3%)
Asthma	591 (1.1%)	$2.29 (13.0%)
Chronic obstructive pulmonary disease (COPD)	18,411 (34.4%)	$3.94 (22.3%)
Pulmonary tuberculosis	25 (<0.1%)	$0.07 (0.4%)
Cancer		
Lung cancer	15,366 (28.8%)	$1.38 (7.8%)
Bladder cancer	1642 (3.1%)	$0.46 (2.6%)
Mesothelioma	2194 (4.1%)	$1.87 (10.6%)
Leukemia	369 (0.7%)	$0.14 (0.8%)
Laryngeal cancer	313 (0.6%)	$0.08 (0.5%)
Skin cancer	66 (0.1%)	$0.07 (0.4%)
Sinonasal cancer	116 (0.2%)	$0.05 (0.3%)
Nasopharynx cancer	148 (0.3%)	$0.02 (0.1%)
Kidney cancer	93 (0.2%)	$0.01 (0.1%)
Liver cancer	79 (0.1%)	$0.005 (<0.1%)
All cancers combined	20,386 (38.1%)	$4.10 (23.2%)
Circulatory disease		
Coronary heart disease due to job control, shift work, or noise[a]	9,809 (18.4%)	$4.58 (25.9%)
Coronary heart disease due to environmental tobacco smoke[a]	2,415 (4.5%)	$1.44 (8.2%)
Stroke due to noise[a]	80 (0.1%)	$0.06 (0.4%)
All circulatory diseases	12,304 (23.0%)	$6.09 (34.5%)
All other diseases		
Renal disease	636 (1.2%)	$1.01 (5.7%)
Liver disease from hepatitis B and C	107 (0.2%)	$0.11 (0.6%)
Subtotal for fatal diseases	53,445	$17.66
Nonfatal disease cases	462,704	$3.17
Total for fatal and nonfatal diseases	516,149	$20.83

Notes: [a]Steenland and colleagues (2003) created two categories for occupational coronary heart disease based on causes (job control, shift work, or noise versus environmental tobacco smoke) and one category for stroke (noise). Owing to rounding, columns and rows may not sum.

Sources: For fatal diseases, AHRQ 2010; CDC 2009; Hartman et al. 2009; Rice, Hodgson, and Kopstein 1985; Schappert and Rechtsteiner 2008; Steenland et al. 2003. For nonfatal cases: NCCI 2008; U.S. Bureau of Labor Statistics 2010a, 2010b, 2010c, 2010d, 2011a.

TABLE 3
Estimated Medical and Indirect Costs of Occupational Injuries and Diseases, 2007

Category	Injury Costs in $Billions and Percentage (of row)	Disease Costs in $Billions and Percentage (of row)	Total Injury and Disease Costs (in $billions)
Medical	$46.26 (69.0%)	$20.83 (31.0%)	$67.09
Fatalities	$0.31 (1.7%)	$17.66 (98.3%)	$17.97
Nonfatalities	$45.95 (93.5%)	$3.17 (6.5%)	$49.12
Indirect	$145.574 (79.7%)	$36.971 (20.3%)	$182.54
Lost earnings	*$91.00* *(82.7%)*	*$19.02* *(17.3%)*	*$110.02*
Fatalities	$3.55 (21.9%)	$12.67 (78.1%)	$16.22
Nonfatalities	$87.45 (93.2%)	$6.35 (6.8%)	$93.80
Fringe benefits	*$24.30* *(83.7%)*	*$4.73* *(16.3%)*	*$29.03*
Fatalities	$0.95 (19.6%)	$3.89 (80.4%)	$4.84
Nonfatalities	$23.35 (96.5%)	$0.85 (3.5%)	$24.20
Home production	*$30.27* *(69.6%)*	*$13.22* *(30.4%)*	*$43.49*
Fatalities	$1.18 (9.4%)	$11.33 (90.6%)	$12.51
Nonfatalities	$29.09 (93.9%)	$1.89 (6.1%)	$30.98
Total for medical and indirect costs	$191.83 (76.8%)	$57.81 (23.2%)	$249.64

Note: Owing to rounding, columns and rows may not sum.

Sources: For fatal diseases, AHRQ 2010; CDC 2009; Hartman et al. 2009; Rice, Hodgson, and Kopstein 1985; Schappert and Rechtsteiner 2008; Steenland et al. 2003. For nonfatal cases: NCCI 2008; U.S. Bureau of Labor Statistics 2010a, 2010b, 2010c, 2010d, 2011a.

injuries were for nonfatal cases, whereas the opposite was true for diseases. Medical costs for injuries were concentrated in nonfatal cases (largely because of the costs associated with permanent disabilities), whereas fatal cases accounted for most of the cost of occupational diseases (largely because of the greater ratio of deaths to nonfatal cases for illnesses than for injuries). One disparity was especially sharp: for medical costs for fatalities, 1.7 percent were for injuries, whereas 98.3 percent were for diseases. A similar pattern, although less noticeable, was observed for the indirect costs of fatalities. For example, for lost earnings, 21.9 percent was attributed to injuries and 78.1 percent, to diseases. Compared with lost earnings, lost home production percentages were significantly lower for fatal injuries (9.4%) and relatively higher for fatal diseases (90.6%). The greater losses generated by diseases for home production reflected the greater percentage of women dying from occupational diseases (16%; Nurminen and Karjalainen 2001) versus injuries (8%; U.S. Bureau of Labor Statistics 2011a) and the greater per-person contribution to home production contributed by women versus men (Grosse 2003). Within only indirect productivity costs, lost earnings contributed 60.3 percent; lost fringe benefits contributed 15.9 percent; and lost home production contributed 23.8 percent. Table 3 also shows the significant contrast between the high numbers and costs of nonfatal injuries and the low numbers and costs of nonfatal illnesses. These findings are consistent with those of previous studies (Leigh and Robbins 2004). In part, this contrast is due to the difficulty of assigning blame to job exposures for illnesses that have long latencies, as opposed to the ease of assigning blame to injuries that are immediate (Ruser 2008). Finally, the data in table 3 reveal that the estimate for medical and lost earnings only—the most basic categories that are included in virtually all cost-of-illness studies—was $177.11 billion.

Table 4 gives the costs by broad categories for injuries and diseases, fatal and nonfatal, and medical and indirect costs. The sharpest contrasts are for deaths. Diseases were responsible for nearly ten times as many deaths as injuries were. The percentage of medical costs for deaths due to diseases was more than seven times larger than that for injuries. In contrast, the percentage contribution to lost productivity for disease deaths was much lower than that for injury deaths. These results indicate that injury deaths tended to be quick, not involve much medical care, and also to occur in relatively young persons, at least younger than the many retired persons who died of occupational diseases. Deaths of

TABLE 4
Estimated Medical and Indirect Costs of Fatal and Nonfatal Occupational Injuries and Diseases, 2007

Category	Number	Medical Costs in $Billions and Percentage (for row)	Indirect Costs in $Billions and Percentage (for row)	Total Costs for Row in $Billions and Percentage (in column)
Injuries	8,564,619	$46.26 (24.1%)	$145.56 (75.9%)	$191.83 (76.8%)
Fatalities	5,657	$0.31 (5.2%)	$5.68 (94.8%)	$5.99
Nonfatalities	8,558,962	$45.95 (24.7%)	$139.89 (75.3%)	$185.84
Diseases	516,149	$20.83 (36.0%)	$36.98 (64.0%)	$57.81 (23.2%)
Fatalities	53,445	$17.66 (38.8%)	$27.89 (61.2%)	$45.55
Nonfatalities	462,704	$3.17 (25.9%)	$9.09 (74.1%)	$12.26
Total costs for injuries and diseases		$67.09 (26.9%)	$182.54 (73.1%)	$249.64

Note: Owing to rounding, columns and rows may not sum.

Sources: For fatal diseases, AHRQ 2010; CDC 2009; Hartman et al. 2009; Rice, Hodgson, and Kopstein 1985; Schappert and Rechtsteiner 2008; Steenland et al. 2003. For nonfatal cases: NCCI 2008; U.S. Bureau of Labor Statistics 2010a, 2010b, 2010c, 2010d, 2011a.

younger persons generated more lost indirect productivity costs than did deaths of older persons. Whereas indirect costs comprised roughly 76 percent for injuries, they comprised 64 percent for diseases. This cost differential reflected the relatively greater number of nonfatal injuries compared with nonfatal illnesses and the older age of deaths for diseases versus injuries. Overall, medical costs contributed nearly 27 percent, and lost productivity contributed 73 percent.

The sensitivity analysis appendix addresses the assumptions and parameter values with the most consequence. These assumptions and parameters, in order of magnitude, pertained to underreporting rates, wage-replacement rates, insurance administrative costs, numbers of disease deaths (especially from circulatory diseases), job-related osteoarthritis, percentage of SOII cases in the three-to-five-days-lost categories, employers' turnover costs, and morbidity costs for fatal diseases. The sensitivity analysis also estimates a range of total costs from $145 billion to $401 billion.

Discussion

Estimates of cost of illness for cardiovascular disease, cancer, diabetes, and COPD, among others, frequently appear in the literature (Foster et al. 2006; Petersen and the American Diabetes Association 2008; Rosamond et al. 2007, 2008). But these are single-disease estimates and require analysis of perhaps one to four primary data sources. Estimates of occupational injury and illness are rarer, in part, because they require analysis of far more primary data sources and scores of secondary sources, combine fatal with nonfatal injuries, and need data on eighteen or more diseases.

The total cost of approximately $250 billion for occupational injuries and diseases is comparable to the total cost of major diseases and injuries. Rosamond and colleagues (2007, 2008) calculated the 2007 medical and indirect costs to be $431.8 billion for cardiovascular disease, $219 billion for cancer, $151.6 billion for coronary heart disease, and $62.7 billion for stroke. The $219 billion figure for 2007 was also prominently displayed on earlier versions of the American Cancer Society's website (2011). Rosamond and colleagues' estimates (2007, 2008) were generated by Thomas Thom and Wendy Max. Rosamond and colleagues' description (2007, e169), as well as personal correspondence with Wendy Max, confirms that their methods were identical to those that I used. For example, for fatal diseases, I applied the prevalence rather than the incidence method, and the costs included medical and indirect categories but excluded administrative and turnover costs. In addition, both this study and Rosamond and colleagues' (2007, 2008) studies have indirect categories that include lost wages, lost fringe benefits, and lost home production, and both measure years of life and production lost owing to morbidity.

Petersen and the American Diabetes Association (2008) estimated the medical and indirect costs of diabetes to be $174 billion in 2007. Their methods were similar to mine: we both used the prevalence method, included payments for hospitals and physicians in medical costs, and included lost productivity at work in indirect costs. But there are some differences. Petersen and the American Diabetes Association (2008) estimated "excess" medical costs so that, for example, costs associated with comorbidities such as obesity were excluded. Petersen and the American Diabetes Association (2008) also calculated declines in work performance due to diabetes while at work—so-called presenteeism. While commendable, there is no consensus on the implementation of methods to measure "excess" costs or "presenteeism." In any case, implementation of these methods in this study, which combined job-related injuries with eighteen diseases, was not possible with existing data.

Foster and colleagues (2006) provided a literature review of the costs of COPD. I converted the medical and indirect cost estimate they cited most often to 2007 dollars, or $43.6 billion. This estimate was from the National Heart Lung and Blood Institute, which in turn took it from the same sources as in Rosamond and colleagues' (2007, 2008) studies.

I also converted Corso and colleagues' (2006) figures from 2000 to 2007 dollars, or $596 billion in medical and indirect costs for all injuries, including job-related ones. Both Corso and colleagues' (2006) study and this one used the incidence rather than the prevalence method to estimate injury costs.

This study's medical costs percentages were significantly lower, and the indirect costs were significantly higher, than those for the literature estimates for diseases. The literature's estimates for cancer, for example, were 40.6 percent for medical costs and 59.4 percent for indirect costs (American Cancer Society 2011). In this study, medical costs accounted for 26.9 percent, and indirect costs, 73.1 percent. The reason for the difference was that the higher percentages of my study's costs were derived from injuries afflicting disproportionate numbers of working-aged persons, compared with the costs of fatal diseases afflicting disproportionate numbers of retired persons. This study's percentages were closer to those for all injuries in Corso and colleagues' (2006) study: 19.7 percent for medical costs and 80.3 percent for lost productivity.

The numbers of deaths can also be compared with those of different studies. I estimated 59,102 deaths from occupational injuries and diseases combined, which was lower than the 2007 estimates for deaths from cancer (562,875), stroke (135,952), and COPD (127,924), but higher than for deaths from motor vehicle crashes (43,945), breast cancer (40,970), prostate cancer (29,093), homicide (18,361), and HIV/AIDS (11,295) (Xu, Kochanek, and Murphy 2010).

My estimate of the cost of occupational injury ($192 billion) is similar to the National Safety Council (NSC)'s 2007 estimate of $175 billion for medical and indirect costs (NSC 2009). The NSC, however, does not count assaults or murders.

Nationwide, workers' compensation paid $55.4 billion in medical payments and indemnity benefits in 2007 (Sengupta, Reno, and Burton 2009). The disparity between my estimate ($249.6 billion) and the $55.4 billion from workers' compensation was wide, reinforcing the view that workers' compensation does not cover the full costs of occupational injury and illness. But workers' compensation was not designed to provide complete restitution. For example, state laws rarely, if ever, allow indemnity payments to exceed 70 percent of wages. These indemnity requirements also eliminate the possibility of covering fringe benefits or home production. Lack of full coverage, nevertheless, has also been attributed to the inadequacy of workers' compensation benefits. Studies suggest that workers' compensation pays considerably less than the oft-cited standard of 66 percent of wages (Boden, Reville, and Biddle 2005), does not record from 23 to 91 percent of injuries (Biddle et al. 1998; Bonauto et al. 2010; Lakdawalla, Reville, and Seabury 2007), and does not pay for more than 95 percent of fatal diseases (Leigh and Robbins 2004).

This study's estimates may be compared with the 1992 figure of $146 billion (or $217 billion in inflation-adjusted dollars) (Leigh et al. 1997) for all occupational injuries and illnesses, excluding administration and turnover costs. Using similar methodology, this study's $250 billion for 2007 suggested a 71 percent increase from 1992 to 2007. There were broad economic and epidemiologic trends from 1992 to 2007 and several improvements in methods between the two studies that explain this increase. The broad trends driving up costs included 84 percent medical inflation and 48 percent general inflation (U.S. Bureau of Labor Statistics 2011b); employers' greater spending on fringe benefits due to rapidly rising health insurance premiums (U.S. Bureau of Labor Statistics 2011b); greater life expectancy resulting in more indirect costs (CDC 2009); and significant increases in the prevalence of COPD and asthma deaths (CDC 2009). But there also were broad trends driving down costs: a 36 percent decline in reported nonfatal injuries and an 11 percent decline each in fatal injuries and diseases. Because the number of nonfatal injuries fell more than did the number of fatal diseases, the percentage of costs attributed to diseases in 2007 (23%) exceeded that in 1992 (15%).

Changes in methodology also increased the cost estimates. First, the 2007 estimate valued home production at 26 percent of lost earnings (Grosse 2003), whereas the 1992 estimate valued it at 14 percent. This more than double the figure for home production was due in part to the greater percentage of women in the workforce in 2007 than in 1992 and the subsequent increase in the opportunity cost of their time in home production. This 26 percent was consistent with recent evaluations of the estimates of the costs of cancer (Yabroff et al. 2008). Second, the 2007 estimate of morbidity costs was nearly three times the size of the 1992 estimate because the 1992 estimate failed to account for the morbidity costs of fatal diseases before death. Third, the 2007 estimate for circulatory disease was more than three times higher than the 1992 estimate in part because Steenland and colleagues' AF estimate (2003) included deaths up to age sixty-nine, whereas the 1992 estimate was only up to age sixty-five. Additional discussion of the differences between the 1992 and 2007 estimates appear in the unpublished appendix (available from me on request). We can compare the numbers of disease deaths in the 1997 study by Steenland and colleagues (2003) and my study's 2007 estimates. Steenland and colleagues (2003) estimated between 25,910 and 72,121 deaths. In this study's unpublished appendix, the range was between 27,508 and 79,377. Most of the rise in the total number of disease deaths from 1997 to 2007 was due to increases in all COPD deaths, whether or not they were occupational. Steenland and colleagues (2003) estimated between 5,092 and 24,440 deaths, and I estimated between 6,349 and 30,473 for job-related COPD.

Limitations

The sensitivity analysis appendix addresses the most consequential limitations, but there were others. I assumed that the 2005 death statistics applied to those for 2007, likely resulting in underestimates for COPD and asthma but in overestimates for coronary disease and stroke. This study did not include nervous systems disorders, dementia, or depression. But these are controversial inclusions, and they would have amounted to less than 1 percent of the total costs (Leigh, Yasmeen, and Miller 2003). Steenland and colleagues (2003) calculated fewer cancer AFs than did Nurminen and Karjalainen (2001), but the latter relied on studies of worker exposures outside the United States. When calculating the indirect costs of fatal diseases, this study allowed only two age categories: <65 and 65+. The 65+ category, however, is not controversial because work productivity is low for the great majority of persons over the age of sixty-five, and the average ages chosen for the <65 category—for example, ages thirty-five to thirty-nine and forty-five to forty-nine—were reasonable given the lower bounds of twenty and thirty. Finally, my reliance on Steenland and colleagues' AFs may have resulted in underestimates. As they cautioned (2003, 461), "Our estimate is in the range reported by previous investigators, although we have restricted ourselves more than others to only those diseases with well-established occupational etiology, biasing our estimates conservatively."

I did not estimate costs using large nationally representative data sets of individuals and econometric techniques (Yelin et al. 2004). But no national data sets with which I am familiar are as comprehensive as the SOII and the CFOI for measuring occupational injuries and the NCCI for measuring actual costs incurred by insurance companies. Nor do they have information on such diverse diseases as pneumoconiosis, ten different cancer sites, or hepatitis B and C. Moreover, I did not use the friction method to estimate indirect costs (Koopmanschap et al. 1995). The friction method measures firms' costs associated with hiring replacement workers. Although this method may be appropriate for individual firms, it is not from this study's societal perspective, which assumes that replacement workers eventually would have found other jobs (especially over a lifetime) and that injured, ill, or deceased workers would have contributed to economic output had they not experienced injuries or illnesses or died. In addition, the friction method requires extensive data on levels of unemployment across regions, occupations, industries, and years. In part because of the heavy data requirements, neither the econometric approach nor the friction method has been used for the most popular estimates of the cost of illness for cancer, heart disease, COPD, or others. Finally, although the sensitivity analysis considered varying underreporting rates, the amount of fraud by workers was not explicitly estimated. I am not aware of any scientific study of the extent of worker fraud in workers' compensation. One study on a related program, unemployment insurance (UI), conducted during the Bush Administration, estimated "fraud and abuse" to be a modest 1.9% of total UI spending (US General Accounting Office, 2002). But any analysis of worker fraud should also consider illegal activities by insurance carriers to deny legitimate claims. Again, I am not aware of studies on insurance carriers.

There were broader limitations. This study did not include the costs of pain and suffering, even though they might have exceeded medical and indirect costs combined (Posner and Sunstein 2005). Indeed, pain and suffering can be terrible for a child when a sudden injury death claims a parent. This study did not count home care provided by family members, which is substantial. And it did not include estimates for lost "presenteeism" or for undiagnosed disease (Petersen and the American Diabetes Association 2008). However, the majority of cost-of-illness studies of nonoccupational diseases, including those cited earlier, do not include pain and suffering, costs for family caregivers, or undiagnosed diseases. Finally, numerous studies link poverty and income inequality to health (Lynch et al. 2000). Because significant amounts of income come from jobs, it is likely that low wages affect health (Fletcher, Sindelar, and Yamaguchi 2011; Kim and Leigh 2010). This study, however, did not account for low-wage effects.

Strengths

This study improved on the 1992 study. The 2007 estimates relied on actual BLS data rather than researchers' estimates for state and local government workers. This 2007 study also used actual rather than estimated BLS numbers for one to two days of work loss. This is significant because all states require at least three workdays lost before workers can receive compensation indemnity benefits. I generated unique estimates of the numbers of injuries for farmworkers and the self-employed rather than relying on unadjusted general BLS rates that did not include the great majority of farmworkers and none of the self-employed. This study also allowed for more coverage by workers' compensation systems than by BLS and included NCCI data on forty-six rather than forty states. My 2007 estimate relied on more recent estimates of attributable fractions (AFs), and some AFs distinguished between men and women. I used data on dollar costs within hospitals, as opposed to days in hospital. The 2007 study looked at ten cancer sites, whereas the 1992 study looked at only the single, broad, cancer category. This study included hepatitis and adjusted asthma, COPD, and other diseases for outpatient and inpatient cost differences, and it contains specific estimates of the effects of job strain, shift work, noise, and secondhand smoke on coronary heart disease. I calculated fringe benefits with weighted averages from varying benefits across industries. Finally, I estimated the cost of job-related osteoarthritis.

This 2007 study has advantages over other cost-of-illness studies. I relied on the longest-running and most widely used data set on U.S. injuries: the BLS's Survey of Occupational Injuries and Illnesses (SOII), and I used NCCI data on per-injury costs from more than nine hundred insurance carriers in thirty-six to forty-six states. Finally, unlike many cost-of-illness studies with no sensitivity analyses, I analyzed ten different scenarios.

This study, unlike Corso and colleagues' (2006), did not use either the Medical Expenditure Panel Study (MEPS) or the National Health Interview Survey (NHIS). Both the MEPS and the NHIS require that an injured person seek medical care in order to be categorized as injured. Many work-injured persons, however, do not seek medical care. For example, even though back injuries are the single largest category of work-related injuries, people with back problems frequently avoid medical providers. Lipscomb and colleagues (2009) found that roughly 60 percent of persons in their sample of a fifteen-year cohort of union carpenters with back injuries did not seek medical care from either union-provided health insurance or workers' compensation. The BLS-SOII does include injuries that need not be medically treated provided that they result in a loss of consciousness, more than one workday lost, or restricted work or job transfer; the BLS-SOII, therefore, includes many back injuries.

Occupational injury and illness costs are substantial. In part, this is because roughly 153 million people were working in 2007 and because virtually every job carries some risk of injury or disease. Most Americans between the ages of twenty-two and sixty-five spend 40 to 50 percent of their waking hours at work. Some of these costs are borne directly by employers through workers' compensation premiums. But because workers' compensation benefits cover less than 25 percent of these costs, all members of society must share them. Taxpayers pay through Medicare and Social Security Disability Insurance. Employers and individuals pay through high premiums for nonworkers' compensation insurance carriers, which absorb some of the excess medical costs. Injured workers and their families pay through out-of-pocket medical costs as well as lost wages, fringe benefits, and home production. Whereas the total estimated medical and indirect costs of occupational injury and illness are less than those of cardiovascular disease, they are on a par with cancer, and more than those of diabetes, coronary heart disease, stroke, or COPD. But despite these high costs, occupational injuries and illnesses do not receive the same research, medical, or public attention as other diseases do. This is unfortunate because cost-effective medical care requires that resources be allocated to their most beneficial use.

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Methodology Appendix

Counting and Costing Nonfatal Injuries

The U.S. Bureau of Labor Statistics' (BLS) Annual Survey of Occupational Injuries and Illnesses (SOII) had data on state and local government employees from twenty-six states only. I multiplied the rates (injuries per employee) from these twenty-six by the numbers of state and local employees from the missing twenty-four states and the District of Columbia. The twenty-six states with BLS data—listed in an unpublished appendix available from me—appeared to be representative of the nation.

I also made adjustments to account for the SOII's restrictions regarding farmworkers and self-employed persons. Self-employed farmers and workers on livestock and crop farms with fewer than eleven employees were assumed to have the same injury rate as those on farms with more than eleven employees. For nonfarming self-employed persons, I developed weighted averages that multiplied varying numbers of self-employed persons across broadly defined industries by the rate of injuries for employees in those same industries. These industries were forestry, logging, and fishing; mining; construction; manufacturing; wholesale and retail trade; transportation and public utilities; information; finance;

professional and business services; and education and health services. It is not clear whether these assumptions would lead to over- or underestimates. On the one hand, the self-employed face greater risks of job-related injury deaths than employees do (Pegula 2004). But on the other hand, fatal injuries may not be correlated with nonfatal injuries, and employees may be more inclined than business owners to report nonfatal injuries (Azaroff, Levenstein, and Wegman 2002). For all other "out-of-scope" workers in the SOII (e.g., domestics), I multiplied the average SOII injury rate by the number of employed persons "out of scope." Again, it is not clear whether this assumption imparts a positive or negative bias, but any bias is likely to have little effect because "out-of-scope" workers comprised less than 0.5 percent of the workforce.

The SOII does not provide cost data. The NCCI offers information on current and forecasted costs from more than nine hundred insurance companies in thirty-six to forty-six states. But the NCCI data are published within workers' compensation, not the SOII categories (NCCI 2008). The SOII classification of injuries (0, 1, 2, 3 to 5, 6 to 10, 11 to 20, 21 to 30, and more than 30 days lost) did not match workers' compensation classifications of "medical only," temporary total and partial disability, permanent partial disability, and permanent total disability. I first converted the SOII categories into "medical only" cases versus cases with indemnity benefits and, second, divided the indemnity cases into three disability categories. "Medical only" cases were estimated with BLS categories for zero, one, two, and one-half the number of three to five workdays lost. Cases with indemnity were estimated with BLS categories for one-half the number of three-to-five day cases plus all cases of more than five days. The decision to divide the BLS's three-to-five-day category in half was based on the knowledge that all states have three- to seven-day waiting periods before workers can qualify for indemnity benefits. For ease of presentation, $0 - 4$ will refer to $0 + 1 + 2 +$ (one-half of 3 to 5 days) cases. This study then estimated the number of temporary total cases by multiplying 66.21 percent by the number of indemnity cases. Permanent partial and total were similarly estimated by multiplying the number of indemnity cases by 33.26 percent and 0.53 percent. These 66.21 percent, 33.26 percent, and 0.53 percent figures were derived from NCCI data on the number of cases in these categories per 100,000 workers. These three percentages for 2007 can be compared with three similar percentages from 1992—72.11 percent, 27.44 percent, and 0.45 percent—which were estimated using similar techniques (Leigh et al. 1997).

This study adjusted for a 40 percent underreporting rate. Less severe injuries would more likely be underreported than would more severe injuries. While maintaining an overall underreporting rate of 40 percent, this study assumed that 41 percent and 36 percent of "medical only" and disability cases, respectively, were not reported. Average costs within workers' compensation categories were drawn from the National Council on Compensation Insurance's (NCCI) *Annual Statistical Bulletin*, 2008 edition. Data were available for medical and indemnity (wage-replacement) costs and in varying "reports" depending on the age of the injury. For this study's raw data (before adjustment for inflation), "first reports" were predominantly from 2004/2005 and "third reports" from 2002 through 2004. Costs data were "incurred" (alternatively referred to as "incidence based") meaning that they measured current and discounted future costs of new cases. My decisions regarding which reports to use for which injuries were balanced with my desire for current versus accurate, category-specific data. Because the NCCI does not adjust its data for inflation, "first report" data suffered less from inflation but included more forecasted costs than, for example, "third report" data do. I used data on "first reports" for "medical only" and deaths, based on reasoning that costs for "medical only" and deaths would likely be fully captured within the first eighteen months after the injury. Data from "third reports" were used for all disability categories, based on the reasoning that disability frequently accrues costs for years after the injury. "Fifth reports" were judged to be too far into the past and therefore more likely than recent "reports" to contain irrelevant cost estimates of antiquated medical procedures.

The National Council on Compensation Insurance (NCCI 2008) provides aggregate per-case costs within workers' compensation categories for thirty-six states and the District of Columbia as well as per-case estimates for ten additional states separately (California, Delaware, Massachusetts, Michigan, Minnesota, New Jersey, New York, Pennsylvania, Texas, and Wisconsin). I combined the aggregate estimates with weighted averages from the ten states to obtain average estimates for forty-six states and the District of Columbia combined. The weights were the percentage of the population residing in the ten states out of the total for the forty-six states and the District of Columbia. These combined average costs were assumed to represent the nation. Exclusion of information from four states (North Dakota, Ohio, Washington, and Wyoming) was unlikely to impart significant bias because these states represent only roughly 6 percent of the U.S. population (U.S. Bureau of the Census 2010). All costs were inflated to 2007 dollars, with the BLS's Consumer Price Index for medical prices and its Employer Cost Index for indemnity benefits (U.S. Bureau of Labor Statistics 2011b). The medical costs per case were $935 for "medical only," $8,046 for temporary total, $49,925 for permanent partial, and $681,615 for permanent total.

Using medical cost estimates for workers' compensation may overestimate actual medical costs for injuries not covered by workers' compensation (Baker and Krueger 1995). I therefore assumed that the average medical costs for nonworkers' compensation cases were 10.02 percent less than those for workers' compensation (Baker and Krueger 1995).

Whereas most cost-of-illness studies do not include them, this study estimated administrative costs and included them in one scenario of the sensitivity analysis. Administrative costs (and percentages of medical costs) were calculated for four groups: injuries covered by workers' compensation (47.69%), injuries covered by employer-provided health insurance or other nonworkers' compensation private insurance (15.13%), injuries covered by government insurers (5.67%), and injuries covered by out-of-pocket funds (0%). The workers' compensation administrative percentage was derived from ratios of premiums to benefits for 2001 through 2006 (NCCI 2008; Sengupta, Reno, and Burton 2009). The nonworkers' compensation administrative percentages came from estimates for all national medical spending. I calculated the average percentage for "program administration" for private insurance to be 15.13 percent for 2002, 2004, and 2007 combined (Hartman et al. 2009; Levit et al. 2004; Smith et al. 2006). An identical procedure was adopted to estimate government administration costs using national data for the same three years. I assumed that injuries not covered by workers' compensation were divided among other private insurers, government, and out-of-pocket payers according to the percentage that these three groups contributed to overall national medical spending. These average percentages were 39.68 percent for other private insurers, 45.81 percent for government, and 14.50 percent for out of pocket.

To estimate lost wages for temporary total disability, permanent partial disability, and permanent total disability, I used data on workers' compensation indemnity benefits from the NCCI and assumed the levels for before-tax wage-replacement ratios. This study's most probable assumed ratios were 0.55, 0.35, and 0.45 for temporary total, permanent partial, and permanent total disabilities, respectively. The ratios are easily interpreted. The 0.55 indicates that 55 percent of lost before-tax wages were replaced by indemnity benefits. I relied on before-tax estimates because the cost-of-illness methodology is designed to capture lost economic production, not workers' take-home pay (Rice, Hodgson, and Kopstein 1985). These ratios were derived from an extensive literature review but with preference for estimates in recent studies. Boden, Reville, and Biddle (2005) and Reville and colleagues (2001) found the average replacement rate for permanent partial disabilities to be 39 percent, with a range from 29 to 46 percent across New Mexico, Oregon, Washington, California, and Wisconsin. But these rates were from the 1980s and early 1990s. Guo and Burton (2010) suggested that rates have fallen in recent years. Hunt and colleagues (2004) generated simulations in which replacement rates for temporary total disability were roughly 55 percent, and rates for both permanent disabilities were lower. They concluded (2004, 96), "The wage replacement performance of PPD (permanent partial) benefits has been markedly lower than for other types of benefits." Accordingly, I assumed the lowest rate (35%) for permanent partial disabilities. My sensitivity analysis appendix considers alternative rates.

Replacement rates, however, cannot be applied to cases that are "medical only" but that nevertheless involved one to four days of work lost. For each "medical only" case involving one to four days of loss, I assumed $261.60 in lost wages, which I estimated based on an hourly wage of $15.10 for eight hours over two days. The $15.10 was the 2007 median hourly wage (U.S. Bureau of Labor Statistics 2010c). I assumed that "medical only" cases not involving any work loss did not generate lost wages.

Indemnity payments were assumed to derive from either workers' compensation insurance carriers or governments. Although there is an insurance market for private indemnity payments independent of workers' compensation, it is not large and not likely to figure prominently among those wage earners most at risk for job-related injuries (Sengupta, Reno, and Burton 2009). I used the same administrative cost rate for workers' compensation indemnity benefits as for workers' compensation medical costs. Governments provide benefits through Social Security and state disability programs, and these are significant. For example, in

2007, Social Security Disability Insurance paid more than three times the amount of cash benefits to disabled recipients and their dependents as did workers' compensation nationwide (Sengupta, Reno, and Burton 2009). I thus assumed that the same 5.67 percent that applied to government administration costs for medical care also applied to government administration costs for disability cash payments. A literature review did not uncover any studies that calculated the percentage of job-related injuries that are not compensated by workers' compensation but are compensated by governments. Guo and Burton (2010) suggested that Social Security Disability Insurance is capturing an increasing number of cases that would otherwise qualify for workers' compensation. Therefore, I assumed that one-half the cases that were not covered by workers' compensation were covered by government insurance. This assumption is not terribly consequential, however, because the percentage of administration costs for government is low (5.67%), and the percentage of administrative costs for persons not receiving benefits is zero. Accordingly, I did not use administrative costs in this study's comparisons with other costs of diseases.

The 1997 study by me and my colleagues used an aggregate percentage for fringe benefits across all industries combined. But fringe benefits vary by industry, as do numbers of injuries. I estimated fringe benefits by first accounting for varying amounts based on industry. Fringe benefit data were from the BLS's Employer Cost for Employee Compensation (U.S. Bureau of Labor Statistics 2011b) for nine broadly defined industries. The percentage of total number of injuries contributed by each of these nine was calculated with SOII data. Industry-specific fringe benefit percentages were then multiplied by percentage contributions to total injuries for each industry, and these products were then summed to obtain a weighted-average fringe benefit percentage, 30.89 percent. This percentage, however, contained benefits for paid leave during sickness and supplemental pay, both of which are excluded from fringe benefits calculations in cost-of-illness studies (Grosse 2003). After adjusting for sick and supplemental pay, I calculated that fringe benefits made up 27.4 percent of wages. This 27.4 percent is a little larger than the 22 to 24 percent used by Grosse (2003) and Leigh and colleagues (1997) for data from 2000 and 1992. But because of rising health insurance premiums, fringe benefit percentages have gone up in recent years.

To estimate lost home production, I used data from Grosse's 2003 study, which account for cooking, cleaning, outdoor chores, home and auto maintenance, goods and services, and child care. Grosse's estimates are derived from market payments to nonfamily members who provide home services, and these data have been widely used (Bradley et al. 2008). I multiplied Grosse's ratio of home production costs to wages and fringe benefits (26.25%) by my estimate of lost wages and fringe benefits to calculate home production costs.

Employers' costs for turnover, hiring, and training replacements depend on the length of work time lost by injured workers. Three categories were relevant: zero to four days of work lost, temporary disability, and permanent disability (either partial or total). For zero to four days of work lost, I assumed zero employer turnover costs, reasoning that in this short period of time, employers would not replace the injured worker. Based on formulas in my unpublished appendix using $15.10 for median wages, 2,000 for annual work hours, and ratios of four to twenty-four months for temporary to permanent hiring costs, I estimated $1,450 in hiring and training costs for temporarily disabled workers. For permanently disabled workers, I used the per-lost-worker figure in Wang and colleagues' study (2006), inflated to 2007 dollars ($8,537). Tables 1 through 4 excluded turnover costs because they are excluded from the nonoccupational cost-of-illness studies with which my study will be compared.

Counting and Costing Nonfatal Illnesses

See the text of this article.

Counting and Costing Fatal Injuries

For medical administration, this study first adjusted for numbers of self-employed persons and then applied the same percentages of nonfatal injuries just estimated for workers' compensation insurance, private insurance, and government. Indemnity benefits, if any, accrue to families of the deceased. To estimate administration costs of indemnity for fatal injuries, this study applied the same percentage for permanent total disabilities.

Counting Fatal Diseases

The most recent and most widely cited U.S. study that extensively reviews the epidemiologic literature to generate AFs is that by Steenland and colleagues (2003). The AF represents the "fraction of disease in a population that might be avoided by reducing or eliminating exposure to an etiologic agent, provided that it is causative" (Coughlin, Benichou, and Weed 1994, 51). The formula for AF accounts for the proportion in the general population exposed to the particular agent and the relative risk or odds ratio of death for exposed versus nonexposed groups (Steenland et al. 2003). Although it is beyond the scope of this economic study to review the epidemiologic literature, I will offer a few examples.

The least controversial AF (100%) applies to pneumoconiosis; even the ICD-9 codes themselves use the word *occupational* to define pneumoconiosis. More than one hundred job-related agents, such as dusts, gases, fumes, and vapors, are known to cause asthma. After excluding one outlying study, Steenland and colleagues (2003) used an interquartile range of AFs (11% to 21%) from the review of twenty-one asthma studies by the American Thoracic Society (Balmes et al. 2003). Steenland and colleagues' (2003) 5 to 24 percent AF range for COPD is based on Korn and colleagues' (1987) study, which used a random sample of more than 8,500 men and women in six U.S. cities. Roughly 31 percent were believed to have been exposed to job-related dust. Korn and colleagues (1987) estimated an odds ratio of 1.5 for those exposed to job-related dust versus those not exposed to job-related dust.

Whereas the previous study by me and my colleagues (Leigh et al. 1997) had only one category for cancer, the study by Steenland and colleagues (2003) had ten (see table 2). Bladder cancer is one such category. Carcinogens like 2-naphthylamine and benzidine are sometimes present at job sites. Steenland and colleagues (2003) used Vineis and Simonato's (1991) review of eighteen bladder studies and the corresponding AF range of 7 to 19 percent for men. The 11 percent AF for women is from the case-control study by Silverman, Levin, and Hoover (1990). Leukemia is another job-related cancer, as there is extensive evidence that occupational exposures to benzene, ethylene oxide, and ionizing radiation cause leukemia. Steenland and colleagues (2003) generated AFs for leukemia based on studies indicating relative risks of 2 to 4 for job-related benzene exposure and 1.1 to 3.5 for job-related ethylene oxide exposure, as well as confidence intervals on relative risks for radiation (Blair and Kazerouni 1997; Lynge, Anttila, and Hemminki 1997).

Steenland and colleagues (2003) argued that unlike other job-related diseases such as cancer and COPD, exposures resulting in coronary heart disease (CHD) and stroke are from the recent rather than the distant past. As a result, even though there is no upper age limit for cancer and COPD, Steenland and colleagues (2003) believe that the upper limit for CHD should be age sixty-nine. The three categories are CHD caused by job control, shift work, and noise; CHD among nonsmokers caused by environmental tobacco smoke at work; and stroke caused by noise. Job control is an aspect of job strain and applies to workers' ability to make independent decisions regarding the pace and nature of their tasks. Steenland and colleagues (2003) contended that only job control, not the broader category of job strain, causes CHD. They derived their estimates from combining seven studies that controlled for such conventional risk factors as age and excessive alcohol use. The AF range for job control is 3.8 to 10.4 percent. The AF range for environmental tobacco smoke at work is 4.2 to 6.8 percent but applies only to nonsmokers.

Direct Costs of Fatal Diseases

Calculations are fully described in the unpublished appendix available from me. In this article, COPD hospital costs provide an example. The ratio of COPD hospital charges for those groups aged over thirty to all hospital charges for all diseases and injuries for all age groups was \$11.625 billion / \$966.652 billion = 0.01203. I then multiplied this 0.01203 estimate of the national costs of hospitalizations by the appropriate AF to yield the estimate for job-related hospital costs for COPD: 0.01203 × \$696.5 billion × 14.5% AF = \$1.215 billion. The HCUP estimates for hospitals are for charges, not costs, and therefore cannot be used "as is" to estimate costs. This study assumed that cost-to-charge ratios were equal across job-related diseases.

HCUP hospital data were provided for only certain age groups: <1 year, 1 to 17, 18 to 44, 45 to 64, 65 to 84, and 85+. This study sometimes needed data for different age groups. I estimated the numbers for different age groups with varying assumptions for the diseases. For example, for asthma, I assumed an equal number of cases per year for every year of age from eighteen through forty-four. For cancers, the estimated costs for given age groups were based on the death data for those groups from the CDC mortality reports.

Hartman and colleagues' (2009) data also included "program administration and net cost of private health insurance," which I used to calculate nonworkers' compensation medical administrative costs for diseases. I assumed that the administration costs of nonworkers' compensation indemnity benefits would equal 5.67 percent on one-half the lost wages, that Social Security indemnity benefits would replace one-half the lost wages, and that Social Security administration costs would be the same as all other governments combined, as just estimated.

Indirect Costs for Fatal Diseases

Steenland and colleagues' (2003) estimates were divided into four age brackets: 20+ (asthma), 30+ (nonmalignant respiratory disease, cancer, and chronic renal failure), 20 to 69 (circulatory disease caused by job control, noise, and shift work), and 35 to 69 (circulatory disease due to environmental tobacco smoke). The lost wages, fringe benefits, and home production data were available in five-year brackets, for example, 20 to 24, 25 to 29, and 30 to 34 (Grosse 2003). To match the four gender and age (<65; ≧65) groups, I assumed that the typical asthma death in either men or women in the <65 age group occurred in the 35-to-39 age bracket. In the age ≧65 group, I assumed that the deaths occurred in the 70-to-74 age bracket. Reasoning suggested that asthma kills at relatively younger ages than do other occupational diseases such as COPD and cancer and therefore justified the relatively young, 35-to-39 bracket. The 65-to-69 age bracket was believed to be too young for the ≧65 group, and any bracket over age 75 was believed to be too old. For COPD, tuberculosis, cancer, and chronic renal failure, the lower and upper brackets were assumed to be 45 to 49 and 70 to 74. For circulatory disease caused by job control, noise, or shift work, the lower and upper brackets were assumed to be ages 45 to 49 and 65 to 69. For circulatory disease caused by environmental tobacco smoke, the lower and upper brackets were assumed to be 50 to 54 and 65 to 69. The lower bound for circulatory disease due to environmental tobacco smoke was for older ages (50 to 54) than the lower bound for disease due to job control, noise, and shift work because Steenland and colleagues' (2003) lower limit for tobacco smoke was age 35 but was age 20 for job control, noise, and shift work.

Morbidity costs were for lost wages, fringe benefits, and home production for living persons who could not work because of morbidity associated with fatal diseases. Morbidity costs were therefore in addition to mortality costs because the latter occurred only after death. Morbidity costs were difficult to obtain in the cost-of-illness literature. Recent estimates of costs for categories of circulatory disease and cancer (Rosamond et al. 2007) relied on data in the study by Rice, Hodgson, and Kopstein (1985). They used twelve broadly defined diseases. I mapped occupational diseases into their broadly defined diseases and then multiplied their morbidity-to-mortality ratios per disease by my own estimates of lost wages, fringe benefits, and home production for deaths.

The methodology appendix table describes the strengths and limitations of my major data sources. An unpublished appendix available from me provides greater detail on all sources and calculations.

METHODOLOGY APPENDIX TABLE
Summary of Major Data Sources

Source	Used to Estimate or Analyze	Strengths(+) and Limitations(−)
1992–2007: U.S. Bureau of Labor Statistics 2010a Survey of Occupational Injuries and Illnesses (SOII)	Number of nonfatal injuries and illnesses among employees in private-sector and state and local governments	+ Nationally representative sample from roughly 190,900 private firms, many state and local governments − Omits federal government, domestics − Significant underreporting − Not available in workers' compensation categories
2001–2007: Office of Workers' Compensation Programs 2010	Number of nonfatal injuries and illnesses among civilian employees of federal government	+ Complete records on all federal workers' compensation cases − Not available in workers' compensation categories
2002–2007: U.S. Bureau of Labor Statistics 2010b, 2010c, 2010d	Combine with BLS-SOII to estimate number of nonfatal injuries and illnesses among self-employed, domestics, railroad workers; estimated lost wages and fringe benefits	+ Nationally representative sample of employees and self-employed − Only employment data; no information on injuries or illnesses

Continued

METHODOLOGY APPENDIX TABLE—*Continued*

Source	Used to Estimate or Analyze	Strengths(+) and Limitations(−)
2008: NCCI 2008	Medical costs, indemnity benefits, and lost earnings within workers' compensation categories ("medical only"; temporary, permanent partial, and total disability)	+ Data from 900+ private workers' compensation insurance carriers in 36 to 46 states for 2001 to 2007 − No data from firms that self-insure − No data from single-payer states such as Ohio or Washington
1992–2007: Sengupta, Reno, and Burton 2009	Administrative costs for workers' compensation insurance and general reference for cost comparisons	+ Nationally representative aggregate data on total workers' compensation costs and benefits − No data on per-injury costs within workers' compensation categories
2002–2007: Hartman et al. 2009	National health care spending in categories such as hospitals and pharmaceuticals; Administrative costs for all insurance and governments	+ Nationally representative − No separate data on workers' compensation or job-related injuries
Grosse (2003) and Grosse, Krueger, and Mvundura 2009	Home production for all injuries, illnesses and diseases Earnings and fringe benefits for fatal injuries and diseases	+ Recent data (2007) − No data for persons with only job-related injuries
Wang et al. 2006	Employer costs for hiring, training, and turnover for replacing employees with job-related conditions	+ One of few studies with turnover costs − No data on turnover costs specifically due to job-related injuries
1992–2007: U.S. Bureau of Labor Statistics 2011a Census of Fatal Occupational Injuries	Injury deaths	+ Data from numerous sources including workers' compensation, police, and coroners' reports from 50 states − Requires two confirming reports; may lead to undercount

Continued

METHODOLOGY APPENDIX TABLE—*Continued*

Source	Used to Estimate or Analyze	Strengths(+) and Limitations(−)
Biddle 2009	Combine with NCCI-ASB to estimate costs of fatal injuries	+ Only national estimate within prior 15 years − Estimates from 1998
Attributable fractions (AFs): Steenland et al. 2003	Estimate numbers of job-related disease deaths in 2007	+ Most recent AF estimates for all occupational diseases in the U.S. − Estimates are from 1997
CDC 2009	Combine with AFs to estimate numbers of job-related disease deaths	+ Best national estimate for disease deaths − No AF estimates
AHRQ 2010	Estimate hospital costs by disease; combine with Schappert and Rechtsteiner 2008 to estimate all medical costs	+ Nationally representative sample of hospital discharges and costs by disease − No AF estimates
Schappert and Rechtsteiner 2008	Combine with HCUP to estimate physician visits, drug use, and nursing homes	+ Nationally representative − Broad disease categories, e.g., data on "other neoplasms" but no data on sinonasal cancer − No data on costs
Rice, Hodgson, and Kopstein 1985	Morbidity costs	+ Most widely cited data on morbidity costs − Data from 1980s

Sensitivity Analysis Appendix

The sensitivity analysis table presents alternative estimates that addressed my most consequential assumptions. The alternative scenarios are ranked in order of magnitude. The first pertained to accidental and/or willful underreporting by employers and employees. There is no consensus in the literature regarding the amount of underreporting (Ruser 2008), so I used 40 percent as the most probable estimate. Table 4 of the Boden and Ozonoff (2008) study analyzes six states and three scenarios in which the highest and lowest outlying estimates were eliminated, and reports that the SOII would miss 27 to 57 percent. Rosenman and colleagues (2006) estimated that the SOII missed 67.6 percent in Michigan. Bonauto and colleagues (2010) recently analyzed data from ten states and estimated the percentage of medically treated injuries missed by workers' compensation. The highest was 53 percent missed in Texas, and the lowest was 23 percent in Kentucky. Lakdawalla, Reville, and Seabury (2007) figured that workers' compensation missed from 39 to 74 percent for the most recent years they analyzed (1996, 1998). But workers' compensation systems are alleged to be more thorough than the BLS (Boden and Ozonoff 2008; Nestoriak and Pierce 2009), suggesting that the SOII would have missed more than either 74 or 23 percent. The underreporting phenomenon is not limited to the United States, however. Van Charante and Mulder (1998) found that employers failed to report 64.4 percent of injuries to the government in the Netherlands. In this study, the sensitivity analysis allowed for a 20 percent lower estimate and a 60 percent upper estimate.

The second and third alternatives in the sensitivity analysis apply to the wage-replacement rates assumed for temporary total disability (TTD, 55%), permanent partial disability (PPD, 35%), and permanent total disability (PTD, 45%). The sensitivity analysis allowed for 20 percent decreases and increases in the most probable rates, which resulted in the most probable rates being multiplied by 0.8 and by 1.2.

The fourth scenario added administrative costs for medical and indemnity insurance. The fifth applied to the range concerning the number of disease deaths. I calculated a range based on the AF ranges in Steenland and colleagues' study (2003).

The medical costs of occupational circulatory disease are larger than those for any other occupational disease in table 2. But Steenland and colleagues (2003) ignored hypertensive disease (ICD9 401–404), and the broader effects of job strain as opposed to simply job control, despite significant associations and effects found in the literature (Landsbergis et al. 1994; Schnall et al. 2000). Moreover, Steenland and colleagues (2003) assumed that job-related circulatory disease factors would have no effect after age sixty-nine, despite evidence to the contrary (Leigh and Du 2009). Scenario 6 doubled the costs for circulatory disease. The corresponding number of deaths—24,608—would be more than that for either COPD or cancer, and 24,608 is consistent with Schnall and colleagues' estimates (2000).

Scenario 7 considered job-related osteoarthritis, which can arise from myriad occupational exposures. Cooper and colleagues' widely cited case-control study of 327 men and women (1994) confirmed that repeated knee bending at work is a risk factor for knee osteoarthritis.

Aluoch and Wao's (2009) literature review concluded that jobs involving repeated strain on joints or injuries to joints or jobs that are physically demanding are risk factors for osteoarthritis. Leigh and Robbins (2004) estimated $4.52 billion in medical costs and $4.28 billion in indirect costs in 1999 for job-related osteoarthritis. My 2007 sensitivity analysis assumed that the prevalence of job-related osteoarthritis increased at the same rate as did all arthritis from 1999 to 2007 (+23.9% in Pleis and Lucas 2009); that the medical inflation rate from 1999 to 2007 (+40.8% from U.S. Bureau of Labor Statistics 2011b) applied to medical costs for job-related osteoarthritis; and that the inflation rate for employment costs (+33.2%) applied to all indirect costs. The seventh scenario added job-related osteoarthritis, with $7.89 billion in medical costs and $7.06 billion in indirect costs. The medical costs of $7.89 billion were higher than those for occupational cancer ($4.10 billion).

The eighth scenario considered the assumption pertaining to the number of cases in the BLS's category of three to five workdays lost. Because "medical only" involved fewer costs than did the indemnity cases, this scenario resulted in a decrease in the final estimate.

The ninth scenario indicated that employer turnover, retraining, and hiring costs would have added to the final most probable estimate. Again, even though these were obvious costs, few other cost-of-illness studies include them. The tenth scenario eliminated morbidity costs for the fatal diseases. Although morbidity costs undoubtedly accrued and were included in other cost-of-illness studies (Rosamond et al. 2007), the methodology has not improved since the mid-1980s.

Finally, although scenarios 4 and 9 estimated the administrative and employer costs of turnover, I did not emphasize them. Cost-of-illness studies rarely mention, much less estimate, them. In fact, Biddle (2009) and Petersen and the American Diabetes Association (2008) explicitly state that they ignored these costs.

SENSITIVITY ANALYSIS TABLE

Ten Scenarios Generated Alternative Estimates for Total Costs of Occupational Injury and Illness

Alternative Scenarios and Lower and Upper Bounds	Costs in $Billions and Increase (+) or Decrease (−) over Most Probable Estimate of $249.64 Billion	Percentage Increase (+) or Decrease (−) over Most Probable Estimate
1. Increase of underreporting percentage from 40% to 60%, or decrease from 40% to 20%.	+ or – $39.62	+ or – 15.87%
2. Decrease in workers' compensation wage replacement rates by 20%	+ $37.13	+ 14.87%
• from 55% to 44% for temporary total disabilities		
• from 45% to 36% for permanent total disabilities		
• from 35% to 28% for permanent partial disabilities.		
3. Increase in workers' compensation wage replacement rates by 20%	− $24.76	− 9.92%
• from 55% to 66% for temporary total disabilities		
• from 45% to 54% for permanent total disabilities		
• from 35% to 42% for permanent partial disabilities.		
4. Add medical and indemnity administrative costs.	+ $31.03	+ 12.43%
5. This study's range for disease deaths was 27,508 to 79,377. The upper and lower bounds were 48.5% away from the middle value, 53,445. Apply 48.5% to fatal disease costs.	+ or – $22.09	+ or – 8.85%
6. Double circulatory disease deaths and costs	+ $15.71	+ 6.29%
7. Add job-related osteoarthritis.	+ $14.95	+ 5.99%

Continued

SENSITIVITY ANALYSIS TABLE—*Continued*

Alternative Scenarios and Lower and Upper Bounds	Costs in \$Billions and Increase (+) or Decrease (−) over Most Probable Estimate of \$249.64 Billion	Percentage Increase (+) or Decrease (−) over Most Probable Estimate
8. Change assumption regarding numbers of cases in the BLS 3 to 5 workdays lost category. Most probable assumption was that half of these cases were in the “medical only” category and half were in the disabled category. Sensitivity analysis assumption is that three-fourths now fall into the “medical only” category and one-fourth into the disabled category.	− \$12.85	5.15%
9. Add employer turnover, retraining, and hiring costs.	+ \$6.80	+ 2.72%
10. Eliminate morbidity costs.	− \$5.71	− 2.29%
Lower-bound estimate subtracts all negative amounts.	\$249.64 – \$105.03 = \$144.61 billion	− 42.1%
Upper-bound estimate adds all positive amounts but does not double-count circulatory disease in scenarios 5 and 6.	\$249.64 + \$151.62 = \$401.26 billion	+ 60.1%