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# Economic Burden from Health Losses Due to Foodborne Illness in the United States

**ROBERT L. SCHARFF***

*The Ohio State University, Columbus, Ohio 43210, USA*

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## ABSTRACT

The Centers for Disease Control and Prevention (CDC) recently revised their estimates for the annual number of foodborne illnesses; 48 million Americans suffer from domestically acquired foodborne illness associated with 31 identified pathogens and a broad category of unspecified agents. Consequently, economic studies based on the previous estimates are now obsolete. This study was conducted to provide improved and updated estimates of the cost of foodborne illness by adding a replication of the 2011 CDC model to existing cost-of-illness models. The basic cost-of-illness model includes economic estimates for medical costs, productivity losses, and illness-related mortality (based on hedonic value-of-statistical-life studies). The enhanced cost-of-illness model replaces the productivity loss estimates with a more inclusive pain, suffering, and functional disability measure based on monetized quality-adjusted life year estimates. Costs are estimated for each pathogen and a broader class of unknown pathogens. The addition of updated cost data and improvements to methodology enhanced the performance of each existing economic model. Uncertainty in these models was characterized using Monte Carlo simulations in @Risk version 5.5. With this model, the average cost per case of foodborne illness was $1,626 (90% credible interval [CI], $607 to $3,073) for the enhanced cost-of-illness model and $1,068 (90% CI, $683 to $1,646) for the basic model. The resulting aggregated annual cost of illness was $77.7 billion (90% CI, $28.6 to $144.6 billion) and $51.0 billion (90% CI, $31.2 to $76.1 billion) for the enhanced and basic models, respectively.

Accurate burden-of-illness estimates for foodborne diseases are useful for policy makers and others that seek to characterize and prioritize resources dedicated to addressing the problem of these diseases. Scallan et al. *(14, 15),* in studies conducted for the Centers for Disease Control and Prevention, estimated that approximately 48 million new cases of food-related illness, resulting in 3,000 deaths and 128,000 hospitalizations, occur in the United States annually. These estimates, although confirming that foodborne illness continues to be a problem, are significantly lower than the previous estimates by Mead et al. *(12)* of 76 million cases, 5,000 deaths, and 325,000 hospitalizations. The burden associated with specific pathogens, relative to others, also has changed. For example, *Clostridium perfringens* is now believed to cause more than 26% of food-related bacterial illnesses, in contrast to the less than 6% estimated by Mead et al. *(12).* Because of extensive methodological improvements employed by Scallan et al., it is not clear to what extent, if any, the differences in estimates are driven by true changes in the burden of illness in the population. Regardless of the reason for the differences, the results of the economic burden of foodborne illness studies conducted by Scharff et al. in 2009 *(18)* and Scharff in 2010 *(16),* which were based on the estimates provided by Mead et al. in 1999, are now outdated.

**A comparison of the 2011 and 1999 estimates.** The Scallan et al. *(14, 15)* 2011 estimate for the burden of foodborne illness is not simply an update of the older 1999 Mead et al. *(12)* numbers. Major changes in both methodology and representation of risk are evident in the newer studies. For this reason, although the numbers are smaller, the authors caution readers not to see the difference as representing an overall downward trend in the burden of foodborne illness. Nevertheless, because updated data were included in the Scallan et al. analysis, any trends occurring during this period would have been subsumed in the final numbers presented. For example, most of the increase in the estimated number of cases of *Vibrio vulnificus* infection was due to a more than doubling of identified passive surveillance cases. Important methodological changes in the Scallan et al. study included the introduction of uncertainty, the disaggregation of underdiagnosis and underreporting factors, and the exclusion of travel-related illnesses. The inclusion of uncertainty in the Scallan et al. model is an important improvement that removes the false confidence implied by the Mead et al. point estimates. Scallan et al. estimated a 90% credible interval of 28.7 to 71.1 million illnesses, with a mean of 47.8 million cases. This characterization has the advantage of giving policy

* Author for correspondence. Tel: 614-292-4549; Fax: 614-688-8133; E-mail: scharff.8@osu.edu.

TABLE 1. *Burden of foodborne illness expressed as annual number of cases*[a]

| Disease or agent | No. of illnesses | No. of hospitalizations | No. of deaths |
|---|---|---|---|
| Bacteria | | | |
| *Bacillus cereus* | 63,400 | 20 | 0 |
| *Brucella* spp. | 839 | 55 | 1 |
| *Campylobacter* spp. | 845,024 | 8,463 | 76 |
| *Clostridium botulinum* | 55 | 42 | 9 |
| *C. perfringens* | 965,958 | 438 | 26 |
| STEC O157:H7[b] | 63,153 | 2,138 | 20 |
| STEC non-O157 | 112,752 | 271 | 0 |
| ETEC[c] | 17,894 | 12 | 0 |
| Other diarrheagenic *Escherichia coli* | 11,982 | 8 | 0 |
| *Listeria monocytogenes* | 1,591 | 1,455 | 255 |
| *Mycobacterium bovis* | 60 | 31 | 3 |
| *Salmonella,* nontyphoidal | 1,027,561 | 19,336 | 378 |
| *S. enterica* Typhi | 1,821 | 197 | 0 |
| *Shigella* | 131,254 | 1,456 | 10 |
| *Staphylococcus aureus* | 241,148 | 1,064 | 6 |
| *Streptococcus* group A | 11,217 | 1 | 0 |
| *Vibrio cholerae,* toxigenic | 84 | 2 | 0 |
| *V. vulnificus* | 96 | 93 | 36 |
| *V. parahaemolyticus* | 34,664 | 100 | 4 |
| Other *Vibrio* | 17,564 | 83 | 8 |
| *Yersinia enterocolitica* | 97,656 | 533 | 29 |
| Parasite | | | |
| *Cryptosporidium* spp. | 57,616 | 210 | 4 |
| *Cyclospora cayetanensis* | 11,407 | 11 | 0 |
| *Giardia intestinalis* | 76,840 | 225 | 2 |
| *Toxoplasma gondii* | 86,686 | 4,428 | 327 |
| *Trichinella* spp. | 156 | 6 | 0 |
| Virus | | | |
| Astrovirus | 15,433 | 87 | 0 |
| Hepatitis A | 1,566 | 99 | 7 |
| Norovirus | 5,461,731 | 14,663 | 149 |
| Rotavirus | 15,433 | 348 | 0 |
| Sapovirus | 15,433 | 87 | 0 |
| Total known | 9,388,074 | 55,962 | 1,350 |
| Total unknown | 38,392,704 | 127,839 | 1,686 |
| Grand total | 47,780,778 | 183,801 | 3,036 |

[a] Data from Scallan et al. *(14, 15)*; see these references for estimates of uncertainty associated with these illnesses.
[b] STEC, Shiga toxin–producing *Escherichia coli.*
[c] ETEC, enterotoxigenic *E. coli.*

makers more information upon which to base potentially costly decisions. Scallan et al. also treated the effects of underreporting and underdiagnosis separately. The updated Scallan et al. estimates that were used in this study are presented in Table 1.

**New economic burden of foodborne illness estimates.** The federal agencies that employ economic cost data in regulatory analyses typically use either a basic cost-of-illness model that includes values for medical care, productivity losses, and mortality or a cost-of-illness model enhanced to include pain and suffering values. The former is the method used by the Economic Research Service of the U.S. Department of Agriculture (USDA), and the latter has historically been used by the Center for Food Safety and Applied Nutrition at the U.S. Food and Drug Administration *(6, 20, 22)*. Recently, the USDA Food Safety and Inspection Service has also used the enhanced method in at least one regulatory analysis *(21)*. There are advantages associated with each method. By including a value for pain and suffering, the enhanced model has the advantage of more fully accounting for economic costs associated with foodborne illness. This value is derived by monetizing quality-adjusted life years (QALYs) that have been designed to assess utility loss. The QALYs used in this study were based on individuals' trade-offs between the amount of time with good health and the amount of time with given symptoms and activity limitations (the time trade-off method). This approach yields a measure of the loss of well-being (typically between 0 and 1). Monetized QALY losses are the product of loss of well-being from a condition, the number of days with the condition, and the economic value of 1 day (derived from the value of statistical life) *(23)*. Ideally, this measure would represent the ill consumer's willingness to pay to avoid these pain and suffering losses. However, this only occurs under restrictive conditions, leading to a split in opinion regarding whether this model should be used *(1, 8, 9, 13)*. In contrast, the basic model avoids the controversy over how QALYs should be used but does not provide a value for the legitimate economic costs associated with pain and suffering. In this article, estimates for both methods are provided.

**Rationale and objectives.** Previous estimates of the cost of foodborne illness based on the data of Mead et al. *(12)* are no longer valid following the release of the 2011 Scallan et al. articles *(14, 15)*. Thus, updated estimates are needed. The primary objective of this study was to provide updated estimates of the economic cost of foodborne illness based on an integration of the Scallan et al. and the Scharff et al. *(18)* models. Features of the integrated model include (i) a full replication of the Scallan et al. model; (ii) estimations of economic cost for both the basic and enhanced cost-of-illness model; (iii) use of updated cost data; (iv) employment of methodological improvements to the cost models; (v) characterization of uncertainty; and (vi) characterization of costs at the aggregate level and for specific pathogens.

## MATERIALS AND METHODS

The methodological changes made by Scallan et al. *(14, 15)* clearly affected the predicted number of illnesses from foodborne sources. The Scallan et al. method also led to changes in the burdens associated with illness. These changes are likely to affect both the average cost per case and the aggregated annual social cost of foodborne illness. The following model derives updated estimates of the cost of foodborne illness by combining the model described previously by Scharff et al. *(16, 18)* (including limited methodological changes) with the Scallan et al. model.

**Evaluation of uncertainty.** Uncertainty associated with both the illness and economic components of the model is characterized using Monte Carlo simulation modeling in @Risk version 5.5 (Palisade Corp., Ithaca, NY). The characteristics of the respective models' measures of uncertainty must be accurately preserved because both the Scallan et al. and Scharff models incorporate uncertainty in a comprehensive manner. Given that the cost-of-illness model provides the base, the primary concern is how to accurately incorporate the uncertainty described in the Scallen et al. model. Two options for preserving uncertainty are available. First, one could simply construct Beta distributions that yield values that match the Scallan et al. means and credible intervals (CIs). However, this approach would ignore the shape of the distributions, an important omission given that the combinations of multiple distributions used by Scallan et al. yield, in some cases, multimodal distributions. To most closely preserve the characteristics of uncertainty in the Scallan et al. model, I instead replicated this model using the detailed technical appendices that were made available. My replication of the Scallan et al. model yields similar, though not identical, estimates. My estimate of known illnesses is within 0.1% of theirs, and hospitalizations and deaths are within 2.0 and 0.5%, respectively. These small disparities probably are due to differences in how the Monte Carlo analyses were performed. For the present study, the mean values were adjusted to correspond with the Scallan et al. estimates. This preserves both their values and the underlying distributions they used.

**Two cost-of-illness models.** Both the basic and enhanced cost-of-foodborne-illness models account for health-related economic costs associated with foodborne illness. In the basic model, economic costs from foodborne illness include both financial losses due to medical expenditures and lost productivity and lost utility (well-being) due to death. The losses associated with each given pathogen $i$ are summarized in equation 1:

$$\text{Cost}_i = \text{Hospital}_i + \text{Physician}_i + \text{Pharma}_i + \text{Prod}_i + \text{CProd}_i + \text{VSL}_i + \text{Sequel}_i \quad (1)$$

Medical costs include costs of hospital services ($\text{Hospital}_i$) not including physician care, physician care ($\text{Physician}_i$) including the cost of lab work and both inpatient and outpatient care, and pharmaceutical costs ($\text{Pharma}_i$). Financial costs also are incurred when individuals are not able to work as a result of either their own illnesses or the illnesses of their children ($\text{Prod}_i$ and $\text{CProd}_i$). The value of statistical life ($\text{VSL}_i$) figure used is based on a published meta-analysis of dozens of studies of individuals' trade-offs between fatality risk and money *(23)*. For example, if the most an individual is willing to pay for a reduction in fatality risk of 1/10,000 is \$500, the VSL would be \$5 million (\$500 = VSL/10,000). Because in some cases acute illnesses lead to other often chronic conditions, the costs associated with these conditions are included ($\text{Sequel}_i$). Specifically, costs associated with Guillain-Barre disease (*Campylobacter*), hemolytic uremic syndrome with or without end-stage renal disease (*Escherichia coli*), newborn complications (*Listeria*), and reactive arthritis (*Campylobacter, Salmonella, Shigella,* and *Yersinia*) are included. For each cost measure described above, uncertainty is fully incorporated into the model.

The enhanced cost-of-illness model also incorporates a value for pain and suffering (equation 2):

$$\text{Cost}_i = \text{Hospital}_i + \text{Physician}_i + \text{Pharma}_i + \text{CProd}_i + \text{QALY}_i + \text{VSL}_i + \text{Sequel}_i \quad (2)$$

The difference between the two models is that the enhanced model includes a measure for lost quality of life ($\text{QALY}_i$) but no measure for own-illness productivity loss ($\text{Prod}_i$). $\text{Prod}_i$ is omitted because lost productivity from one's own illness is assumed to be accounted for in the more global $\text{QALY}_i$ value (QALY losses are based in part on functional disability resulting from illness). The QALY variable, when it is used, includes losses from pain, suffering, and functional disability. It is estimated based on the value of a statistical life year (VSLY) adjusted for the number of days ill. VSLY is a measure of the implicit value that individuals place on the loss of a year of life and is estimated as the VSL divided by the discounted ($r$ = 3%) number of life years ($L$) remaining for the average person: VSLY = $(r \times \text{VSL})/[1 - (1 + r)^{-L}]$ *(24)*. For example, if you have an illness that results in a QALY loss of 0.1 for 3 days and the VSLY is \$357,000, the economic loss is calculated as 0.1 × (3 ÷ 365) × \$357,000 = \$293. In the medical literature, QALYs are often implicitly valued at the lower rate of \$100,000 *(10)*. Estimates based on this valuation can be found in the sensitivity analysis.

Details regarding the sources and methods used to derive these costs were described more fully by Scharff et al. *(16, 18)* and in the appendix to this article (http://go.osu.edu/ehe-efa7d). Changes made to these base models are as follows. The most significant changes are based on data presented by Scallan et al. in 2011 *(14, 15)*. Specifically, the new Scallan et al. estimates for

TABLE 2. *Cost per case of foodborne illness by pathogen, 2010*

| | Cost per case (U.S. dollars) | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Productivity loss | | | | Total cost per case | |
| Disease or agent | Medical care | Ill person | Caregiver | Quality of life | Death (VSL) | Prod | QALY |
| Bacteria | | | | | | | |
| *Bacillus cereus* | 49 | 58 | 59 | 126 | 0 | 166 | 234 |
| *Brucella* spp. | 2,663 | 2,782 | 2,855 | 7,178 | 8,857 | 17,157 | 21,553 |
| *Campylobacter* spp. | 216 | 350 | 360 | 6,789 | 776 | 1,846 | 8,141 |
| *Clostridium botulinum* | 106,030 | 20,534 | 21,076 | 357,845 | 1,195,952 | 1,343,592 | 1,680,903 |
| *C. perfringens* | 50 | 73 | 75 | 160 | 197 | 395 | 482 |
| STEC O157:H7[a] | 693 | 398 | 409 | 849 | 8,097 | 9,606 | 10,048 |
| STEC non-O157 | 90 | 398 | 408 | 868 | 0 | 896 | 1,366 |
| ETEC[b] | 58 | 398 | 408 | 868 | 0 | 863 | 1,334 |
| Other diarrheagenic *Escherichia coli* | 58 | 397 | 408 | 869 | 0 | 863 | 1,335 |
| *Listeria monocytogenes* | 59,377 | 1,819 | 1,867 | 46,197 | 1,174,628 | 1,272,279 | 1,282,069 |
| *Salmonella,* nontyphoidal | 401 | 647 | 568 | 7,421 | 2,697 | 4,312 | 11,086 |
| *S. enterica* Typhi | 2,499 | 933 | 861 | 8,128 | 0 | 4,293 | 11,488 |
| *Shigella* | 179 | 555 | 570 | 8,244 | 558 | 1,956 | 9,551 |
| *Staphylococcus aureus* | 87 | 133 | 136 | 289 | 183 | 539 | 695 |
| *Streptococcus* group A | 46 | 645 | 662 | 1,411 | 0 | 1,353 | 2,119 |
| *Vibrio cholerae,* toxigenic | 249 | 618 | 635 | 1,343 | 0 | 1,502 | 2,226 |
| *V. vulnificus* | 40,852 | 848 | 870 | 2,086 | 2,748,273 | 2,790,553 | 2,792,171 |
| *V. parahaemolyticus* | 90 | 500 | 514 | 1,095 | 853 | 1,957 | 2,551 |
| Other *Vibrio* | 91 | 500 | 514 | 1,094 | 3,322 | 4,426 | 5,020 |
| *Yersinia enterocolitica* | 126 | 883 | 906 | 8,125 | 2,176 | 4,186 | 11,334 |
| Parasite | | | | | | | |
| *Cryptosporidium* spp. | 82 | 722 | 741 | 1,581 | 511 | 2,056 | 2,916 |
| *Cyclospora cayetanensis* | 64 | 442 | 453 | 966 | 0 | 958 | 1,483 |
| *Giardia intestinalis* | 70 | 1,060 | 1,088 | 2,324 | 190 | 2,408 | 3,672 |
| *Toxoplasma gondii* | 2,735 | 2,650 | 2,719 | 6,760 | 27,655 | 35,759 | 39,869 |
| *Trichinella* spp. | 718 | 4,328 | 4,442 | 9,945 | 0 | 9,487 | 15,104 |
| Virus | | | | | | | |
| Astrovirus | 105 | 356 | 365 | 776 | 0 | 827 | 1,247 |
| Hepatitis A | 1,213 | 928 | 952 | 2,094 | 32,814 | 35,907 | 37,073 |
| Norovirus | 83 | 122 | 125 | 265 | 200 | 530 | 673 |
| Rotavirus | 188 | 303 | 311 | 654 | 0 | 802 | 1,154 |
| Sapovirus | 77 | 303 | 311 | 661 | 0 | 691 | 1,049 |
| Total known | 171 | 255 | 251 | 1,941 | 1,111 | 1,786 | 3,458 |
| Total unknown | 81 | 240 | 247 | 528 | 322 | 890 | 1,178 |
| Grand total | 99 | 243 | 248 | 805 | 477 | 1,068 | 1,626 |

[a] STEC, Shiga toxin–producing *Escherichia coli.*
[b] ETEC, enterotoxigenic *E. coli.*

hospitalization and death rates replace the older Mead et al. *(12)* estimates that had been used. For most pathogens, Scallan et al. defined the proportion of the population that ''seeks care'' as a variable for their underdiagnosis multiplier. The seeks care variable was used as a proxy for the probability of visiting a doctor, where it has been defined. This seeks care variable is an imperfect proxy because some patients may visit a doctor more than once for an illness, whereas others may visit the emergency room and be hospitalized without first visiting a doctor.

A second set of changes involves updating values to reflect the most recent data available. Estimates of hospital care costs and lengths of hospitalization from the Healthcare Cost and Utilization Project have been updated to include data through 2008 *(2)*. Productivity loss estimates have been updated to reflect the reported average hourly cost of compensation in September 2010 *(5)*. All estimates were updated to 2010 U.S. dollars using the consumer price index relevant to the economic sector at issue (e.g., the consumer price index for physician services was used to inflate 2009 physician visit costs to obtain 2010 values) *(4)*.

The final changes reflect independent improvements to the model. One change involves adjustment of the VSL (based on a 2003 estimate from a widely used meta-analysis) to account for income changes and inflation. In the 2009 Scharff et al. study *(18)*, this value was not adjusted. This simple assumption was replaced in the present study with the 2009 Bellavance et al. *(3)* estimate for the income elasticity of VSL (elasticity is assumed to be uniformly distributed between 0.84 and 1.08). Income elasticity of VSL is defined as the ratio of the percentage change in VSL to the

TABLE 3. *Economic cost of foodborne illness, basic cost of illness model, 2010*

| Disease or agent | Cost per case (U.S. dollars) | | Total cost (millions of U.S. dollars) | |
|---|---|---|---|---|
| | Mean | 90% CI | Mean | 90% CI |
| Bacteria | | | | |
| *Bacillus cereus* | 166 | 78–235 | 11 | 2–28 |
| *Brucella* spp. | 17,157 | 9,305–26,402 | 14 | 8–24 |
| *Campylobacter* spp. | 1,846 | 995–4,110 | 1,560 | 437–4,031 |
| *Clostridium botulinum* | 1,343,592 | 89,000–8,010,000 | 74 | 4–416 |
| *C. perfringens,* foodborne | 395 | 187–1,378 | 382 | 45–1,443 |
| STEC O157:H7[a] | 9,606 | 3,447–23,513 | 607 | 121–1,827 |
| STEC non-O157 | 896 | 845–989 | 101 | 11–273 |
| ETEC[b] | 863 | 842–908 | 15 | 0–41 |
| Other diarrheagenic *Escherichia coli* | 863 | 842–908 | 10 | 0–28 |
| *Listeria monocytogenes* | 1,272,279 | 81,000–3,904 | 2,025 | 95–6,613 |
| *Salmonella,* nontyphoidal | 4,312 | 1,558–10,042 | 4,430 | 1,479–10,881 |
| *S. enterica* Typhi | 4,293 | 2,389–6,925 | 8 | 0–24 |
| *Shigella* | 1,956 | 1,285–5,439 | 257 | 38–768 |
| *Staphylococcus aureus,* foodborne | 539 | 318–1,992 | 130 | 29–434 |
| *Streptococcus* group A, foodborne | 1,353 | 1,342–1,365 | 15 | 0–112 |
| *Vibrio cholerae,* toxigenic | 1,502 | 1,311–1,762 | 0.1 | 0–0.3 |
| *V. vulnificus* | 2,790,843 | 585,000–5,297,000 | 268 | 54–538 |
| *V. parahaemolyticus* | 1,957 | 1,085–4,752 | 68 | 29–169 |
| Other *Vibrio* | 4,426 | 1,573–9,963 | 78 | 28–179 |
| *Yersinia enterocolitica* | 4,186 | 1,899–16,473 | 409 | 69–1,662 |
| Parasite | | | | |
| *Cryptosporidium* spp. | 2,056 | 1,504–4,911 | 118 | 21–394 |
| *Cyclospora cayetanensis* | 958 | 933–1,059 | 11 | 0–39 |
| *Giardia intestinalis* | 2,408 | 2,249–2,617 | 185 | 128–267 |
| *Toxoplasma gondii* | 35,759 | 13,349–62,961 | 3,100 | 1,112–5,726 |
| *Trichinella* spp. | 9,487 | 8,818–10,748 | 1 | 0–4 |
| Virus | | | | |
| Astrovirus | 827 | 794–864 | 13 | 5–22 |
| Hepatitis A | 35,907 | 9,509–68,261 | 56 | 13–125 |
| Norovirus | 530 | 369–709 | 2,896 | 1,545–4,728 |
| Rotavirus | 802 | 730–883 | 12 | 4–21 |
| Sapovirus | 691 | 672–713 | 11 | 4–18 |
| Total known | 1,976 | 894–3,200 | 16,865 | 8,436–29,230 |
| Total unknown | 890 | 619–1,363 | 34,182 | 21,047–51,404 |
| Grand total | 1,068 | 683–1,646 | 51,048 | 31,214–76,142 |

[a] STEC, Shiga toxin–producing *Escherichia coli.*
[b] ETEC, enterotoxigenic *E. coli.*

percentage change in income and is preferred to inflation as an adjustment measure because most VSL studies are based on tradeoffs between risk and wages. VSL increased from $6.7 to $7.3 million between 2003 and 2010. Another change involves how QALY losses are estimated. The previous assumption was that an individual who becomes ill would have been in perfect health (QALY = 1) if not for the illness. However, Luo et al. *(11)* demonstrated that the average QALY in the United States is actually 0.87. As a result, a QALY of 0.689 (representing utility with a mild foodborne illness) now corresponds to a loss of 0.181 QALYs, as opposed to the previously estimated loss of 0.311 QALYs. Useful future research could further refine this measure to account for the preillness QALYs of persons who are afflicted with foodborne illnesses. Another change to the model was the addition of reactive arthritis as a sequela to *Campylobacter, Salmonella, Shigella,* and *Yersinia* infections. Economic costs were estimated based on the estimate by Townes et al. *(19)* for the risk of developing reactive arthritis following foodborne illness, medical cost data, productivity loss data, and QALY loss estimates adjusted to reflect age differences (as reported by FoodNet) using the Scharff and Jessup method *(7, 17)*. The inclusion of arthritis as a sequela increases the expected cost per case of foodborne illness for these pathogens by $99 in the basic model and by $5,979 (for *Campylobacter*) to $7,030 (for *Shigella*) in the enhanced model that includes a measure for pain and suffering.

## RESULTS

Multiple estimates were produced using the specified models. Both the cost per case and the total cost of foodborne illness were determined for each pathogen studied and for foodborne illness as a whole. Although most of the Scallan et al. pathogens were included in the analysis, *Mycobacterium bovis* was not. However, this

TABLE 4. *Economic cost of foodborne illness, enhanced cost of illness model, 2010*

| Disease or agent | Cost per case (U.S. dollars) | | Total cost (millions of U.S. dollars) | |
|---|---|---|---|---|
| | Mean | 90% CI | Mean | 90% CI |
| Bacteria | | | | |
| *Bacillus cereus* | 234 | 37–517 | 15 | 1–46 |
| *Brucella* spp. | 21,553 | 8,097–38,337 | 18 | 7–35 |
| *Campylobacter* spp. | 8,141 | 1,793–19,764 | 6,879 | 1,134–20,129 |
| *Clostridium botulinum* | 1,680,903 | 200,000–8,403,000 | 93 | 10–435 |
| *C. perfringens* | 482 | 162–1,523 | 466 | 56–1,641 |
| STEC O157:H7[a] | 10,048 | 3,241–24,326 | 635 | 120–1,931 |
| STEC non-O157 | 1,366 | 666–2,259 | 154 | 16–467 |
| ETEC[b] | 1,334 | 636–2,222 | 24 | 0–71 |
| Other diarrheagenic *Escherichia coli* | 1,335 | 636–2,226 | 16 | 0–48 |
| *Listeria monocytogenes* | 1,282,069 | 89,000–3,919,000 | 2,040 | 105–6,644 |
| *Salmonella,* nontyphoidal | 11,086 | 2,513–25,615 | 11,391 | 2,459–29,064 |
| *S. enterica* Typhi | 11,488 | 2,706–8,568 | 21 | 0–31 |
| *Shigella* | 9,551 | 1,860–23,609 | 1,254 | 105–4,526 |
| *Staphylococcus aureus* | 695 | 280–2,195 | 168 | 35–507 |
| *Streptococcus* group A | 2,119 | 986–3,565 | 24 | 0–170 |
| *Vibrio cholerae,* toxigenic | 2,226 | 1,126–3,623 | 0.2 | 0.1–0.5 |
| *V. vulnificus* | 2,792,171 | 585,000–5,300,000 | 268 | 54–538 |
| *V. parahaemolyticus* | 2,551 | 908–5,651 | 88 | 29–213 |
| Other *Vibrio* | 5,020 | 1,339–11,159 | 88 | 24–202 |
| *Yersinia enterocolitica* | 11,334 | 2,438–29,157 | 1,107 | 167–3,311 |
| Parasite | | | | |
| *Cryptosporidium* spp. | 2,916 | 1,001–6,756 | 168 | 21–569 |
| *Cyclospora cayetanensis* | 1,483 | 702–2,475 | 17 | 0–63 |
| *Giardia intestinalis* | 3,672 | 1,516–7,107 | 282 | 108–597 |
| *Toxoplasma gondii* | 39,869 | 12,145–72,669 | 3,456 | 1,019–6,606 |
| *Trichinella* spp. | 15,104 | 7,024–25,507 | 2 | 1–6 |
| Virus | | | | |
| Astrovirus | 1,247 | 558–2,396 | 19 | 5–44 |
| Hepatitis A | 37,073 | 9,033–71,112 | 58 | 12–130 |
| Norovirus | 673 | 301–1,106 | 3,677 | 1,424–6,912 |
| Rotavirus | 1,154 | 623–1,866 | 18 | 5–37 |
| Sapovirus | 1,049 | 515–1,766 | 16 | 5–34 |
| Total known | 3,458 | 1,012–7,201 | 32,462 | 9,542–66,780 |
| Total unknown | 1,178 | 499–2,168 | 45,208 | 18,128–84,939 |
| Grand total | 1,626 | 607–3,073 | 77,671 | 28,595–144,599 |

[a] STEC, Shiga toxin–producing *Escherichia coli.*
[b] ETEC, enterotoxigenic *E. coli.*

omission likely has a negligible effect on the overall cost of foodborne illness, given that only 60 domestically acquired cases of foodborne illnesses are annually attributable to this pathogen.

The cost per case for multiple cost categories is presented in Table 2, including the total cost per case for the basic (Prod) and enhanced (QALY) cost-of-illness models. The average cost associated with each case of foodborne illness is $1,068 (90% CI, $683 to $1,646) in the basic model and $1,626 (90% CI, $607 to $3,073) in the enhanced model. The total annual cost attributable to domestic infections from each pathogen (and for all foodborne illnesses) for the basic model is given in Table 3. The total health-related cost of foodborne illness in the United States is $51.0 billion (90% CI, $31.2 to $76.1 billion). The corresponding cost using the enhanced model (Table 4) is $77.7 billion (90% CI, $28.6 to $144.6 billion). The distribution of values produced by Monte Carlo simulation for each model is illustrated in Figure 1.

The uncertainty associated with the economic cost of each foodborne pathogen is provided in Tables 3 and 4. One improvement of the present model over previous models is that it includes uncertainty estimates for both economic factors and predicted illnesses. The result is a larger but more accurate CI for each estimate given. For example, in Scharff's 2010 study *(16)* the 90% CI for the total annual cost of *Yersinia* cases using the enhanced model was $150 to $1,369 million (mean, $674 million). The revised estimate is $1,107 million with a 90% CI of $167 to $3,311 million.

A sensitivity analysis was used to assess the relative effects of uncertain model parameters on the cost-of-illness outputs for the basic and enhanced models. In Figure 2, the

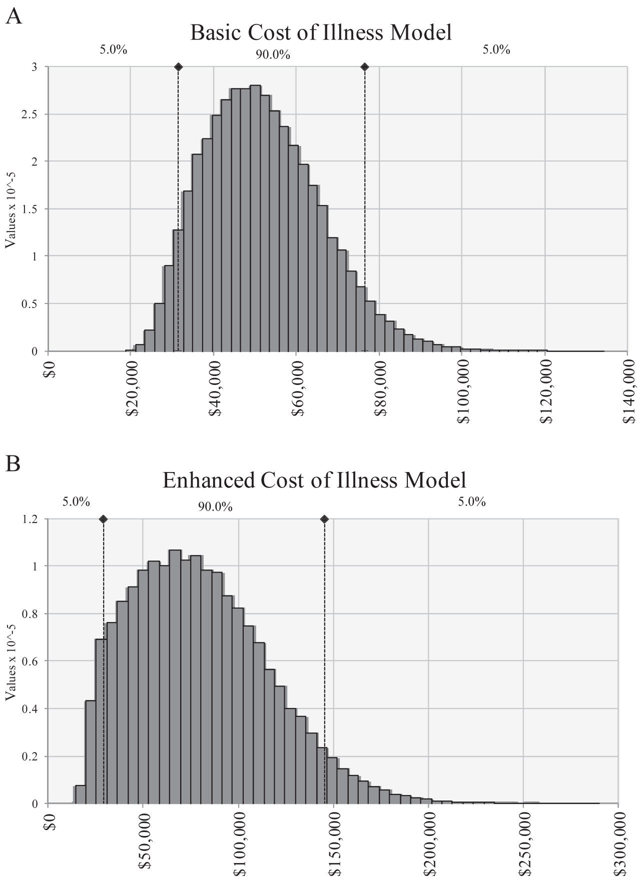


FIGURE 1. *Economic cost of foodborne illness in the United States (values given in millions of U.S. dollars).*

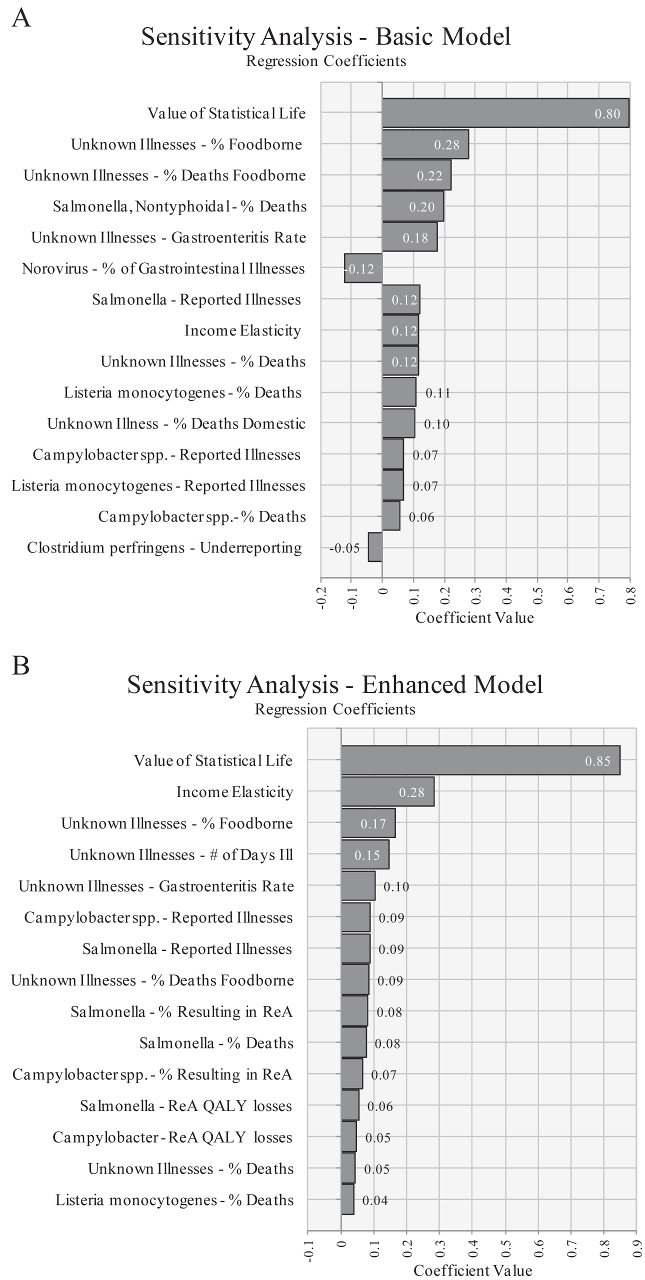


FIGURE 2. *Sensitivity of aggregate cost-of-illness estimates to model inputs.*

15 distributions (of a total of 800 used) that have the greatest effect on cost are illustrated for each model. For both models, the distribution used to estimate the VSL had the largest effect. This finding is not surprising given that death costs for all pathogens in both models (and QALY losses in the enhanced model) were estimated using this distribution. The only other economic measurement that made the list was the (related) income elasticity parameter. The bulk of the parameters that drove the results were related to illness disposition. Those pathogens associated with a high incidence of illness rate (unknown illness, campylobacteriosis, salmonellosis, and norovirus infection) and a high death rate (listeriosis) played a substantial role in each model, although a relatively larger role in the basic model. Conversely, those pathogens causing large quality of life losses, specifically those with large losses from reactive arthritis, played a larger role in the enhanced model (salmonellosis and campylobacteriosis). The importance of both economic and illness disposition distributions in the models illustrates the value of fully incorporating uncertainty for both burden of illness and economic components.

Estimates based on three alternative economic and illness models are shown in Table 5. In the base Scallan et al. model, the values derived in the replication of the Scallan et al. model were adjusted to match the means presented by Scallan et al. The unadjusted model does not include this adjustment. In the population adjusted model, the number of illnesses from the base model (across all categories of pathogen and severity) was proportionally increased to reflect the population increase between 2006 (the year of the Scallan et al. estimates) and 2010. The differences in costs among these models are minimal. For each illness model, three economic models were used. The key difference between these models is whether utility losses from pain and suffering are included. The enhanced model with a full value QALY produced the highest estimated costs, whereas the basic cost-of-illness model and enhanced model with a $100,000 QALY model had the lowest values. Because QALYs are theoretically expected to include aspects of both productivity loss and pain and suffering, these low numbers provide evidence that the $100,000 QALY, which has been used by many researchers, is significantly undervalued.

TABLE 5. *Alternative estimates of the economic cost of foodborne illness, 2010*

| Disease or agent | Cost per case (U.S. dollars) | | Total cost (millions of U.S. dollars) | |
|---|---|---|---|---|
| | Mean | 90% CI | Mean | 90% CI |
| Adjusted to match Scallan et al. | | | | |
| Basic cost-of-illness model | 1,068 | 683–1,646 | 51,048 | 31,214–76,142 |
| Enhanced model with full value QALY | 1,626 | 607–3,073 | 77,671 | 28,595–144,599 |
| Enhanced model with $100,000 QALY | 1,029 | 638–1,620 | 49,158 | 29,695–73,899 |
| Unadjusted | | | | |
| Basic cost-of-illness model | 1,094 | 684–1,710 | 51,300 | 30,844–77,461 |
| Enhanced model with full value QALY | 1,640 | 607–3,096 | 76,855 | 28,005–142,915 |
| Enhanced model with $100,000 QALY | 1,054 | 638–1,686 | 49,392 | 29,302–75,389 |
| Scallan et al. adjusted and population adjusted | | | | |
| Basic cost-of-illness model | 1,068 | 683–1,646 | 52,712 | 32,232–78,623 |
| Enhanced model with full value QALY | 1,626 | 607–3,073 | 80,202 | 29,527–149,312 |
| Enhanced model with $100,000 QALY | 1,029 | 638–1,620 | 50,760 | 30,663–76,307 |

## DISCUSSION

In this study, the estimated cost of foodborne illness was substantial: $51.0 billion in annual health-related costs in the basic model and $77.7 billion in the enhanced model. These values are lower than previous estimates of $102.7 and $151.6 billion, respectively, primarily because of the replacement of the estimates from Mead et al. *(12)* with those of Scallan et al. *(14, 15)*. Scallan et al. revised the total number of annual foodborne illnesses downward by 37% and lowered the probability of hospitalization and/or death from important sources (e.g., infections with *E. coli* O157, *Listeria,* and unknown agents). The improvements made to the economic model also reduced, although to a lesser extent, the overall cost-of-illness estimates. Not all pathogens were associated with a net decline in cost. Revised estimates for 12 pathogens (most notably *C. perfringens,* non-O157 *E. coli, Shigella, Yersinia,* and hepatitis A) had higher total economic burdens than in previous studies.

The costs presented here do not represent the full economic cost of foodborne illness. Although the largest categories of health-related costs have been included, the costs of some sequelae, such as congenital toxoplasmosis, thyroid disease, and postinfectious irritable bowel syndrome, were not examined in this study. Costs of foodborne illness to industry and public health agencies also were not addressed.

Although the estimates presented here are dramatic, there are limits to how these data should be used. The total cost figures are useful as measures of the scope of the problem, but the numbers do not by themselves provide economic justification for any particular program aimed at reducing foodborne illness. Whether a potential food safety program improves social welfare is dependent on three factors: the cost per case of foodborne illness, the number of cases expected to be averted by the program, and the cost of the program to government, consumers, and industry. When examining a particular program, social welfare will only be improved when the product of the cost per case and the number of cases averted exceeds the expected cost of implementing the program for society as a whole. The numbers for cost per case provided here are well suited for use in this type of analysis.

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