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The Cost and Benefit of *Listeria Monocytogenes* Food Safety Measures

RENATA IVANEK and YRJÖ T. GRÖHN

Department of Population Medicine and Diagnostic Sciences, College of Veterinary Medicine, Cornell University, Ithaca, NY, USA

LOREN W. TAUER

Department of Applied Economics and Management, Cornell University, Ithaca, NY, USA

MARTIN WIEDMANN

Department of Food Science, Cornell University, Ithaca, NY, USA

The objectives of this study were to evaluate economic techniques used to determine the cost and benefit of Listeria monocytogenes *control and to estimate the economic optimum of* L. monocytogenes *food safety measures. The level of food safety measures is optimal if marginal benefit and marginal cost equate. Estimates of benefit and cost of* L. monocytogenes *food safety measures, from available published literature, are derived from different methods of economic analysis (willingness to pay, cost of illness, cost function, and event study methods). The estimated annual benefit and cost of* L. monocytogenes *food safety measures range from $2.3 billion to $22 billion and from $.01 billion to $2.4 billion, respectively. The estimated marginal benefit exceeds the estimated marginal cost, which implies that more food safety measures are warranted before the optimal level of* L. monocytogenes *food safety can be reached. However, due to considerable lack of data, the optimal level of* L. monocytogenes *food safety measures could not be estimated. When better data become available, this study can serve as a template for estimating the optimal level of food safety. The understanding of the economic optimum of food safety level will contribute to designing a control program that is economical and acceptable for US society.*

Keywords cost function, cost of illness, event study, foodborne pathogen, optimal level of food safety, willingness to pay

INTRODUCTION

Listeriosis, a foodborne disease caused by the bacteria *Listeria monocytogenes*, is recognized as an important, worldwide public health problem. Incidence of listeriosis in developed countries ranges from 4 to 8 cases per 1,000,000 individuals.[1] Due to its severe character, the hospitalization rate for listeriosis is 92%, while the case fatality rate is 20%.[2] Almost all listeriosis cases (99%) have a foodborne source.[2] According to Mead et al.[2], there are 2,493 foodborne listeriosis cases per year in the US, after adjusting for under-reporting. The population groups most commonly affected by microbial foodborne diseases, including listeriosis, are pregnant women, neonates, the elderly, and people with suppression of the immune system, such as AIDS patients, cancer, or transplant patients.[3] Listeriosis may last from a few days to several weeks.[4] It can develop mild or severe symptoms. Mild cases of listeriosis are characterized by sudden onset of fever, severe headache, vomiting, and other influenza-type symptoms. They may remain undetected by active surveillance. Although relatively mild in pregnant women, listeriosis may cause abortion or can be transmitted to fetuses/newborns, either before or during delivery. Severe cases of listeriosis are often manifested as septicemia and/or meningoencephalitis and may also involve delirium and coma. Listeriosis may cause death in some fetuses, newborns, and adults, or cause developmental complications for fetuses and newborns.

The genus *Listeria* comprises 6 species, among which only the species *L. monocytogenes* is a public health concern. There are some indications though that *L. monocytogenes* subtypes may differ in their ability to cause human illness.[5]

Address correspondence to Renata Ivanek, Department of Population Medicine and Diagnostic Sciences, College of Veterinary Medicine, Cornell University, Ithaca, New York 14853, USA. E-mail: ri25@cornell.edu

L. monocytogenes is a gram (+), psychrotolerant bacteria that can survive and grow for a long period of time in many different environments, including soil and water.[6] It can survive preservation methods, such as the presence of high levels of NaCl (30%) or nitrite concentrations that are allowed in foods. Freezing and storage at −18°C, and even repeated freezing, have little effect on the survival of *L. monocytogenes*; these conditions are more likely to injure than to inactivate this organism.[4] Contamination with *L. monocytogenes* has been found in many kinds of food.[7] The source of food contamination can be in almost any stage of the pre-harvest and post-harvest chain of food production. Entry of *L. monocytogenes* into food processing plants can occur through almost any route, including soil on workers' shoes and clothing and on transport equipment. Furthermore, *L. monocytogenes* can enter the processing plant through animals that excrete the bacterium or have contaminated hides or surfaces, raw plant tissue, raw food (meat, milk) of animal origin, and possibly healthy human *L. monocytogenes* carriers.[4] Moreover, the food contamination can occur at home. If *L. monocytogenes* is present in ready to eat (RTE) food, it may cause listeriosis. That is because RTE food is, by definition, in a form that is edible without washing, cooking, or additional preparation by the food establishment or the consumer, and that is reasonably expected to be consumed in that form.[8]

The current US policy considers the detectable presence (≥1 CFU in 25 gram sample) of *L. monocytogenes* in RTE food to be a health hazard.[9] Regulatory agencies justified this so-called "zero tolerance" policy by limited scientific evidence, stating that any number of *L. monocytogenes* could be consumed without, at least, minimal risk of developing listeriosis.[9] Nevertheless, increasing evidence has been accumulated, showing that low numbers of *L. monocytogenes* represent no considerable health risk for the vast majority of consumers.[10] Because *L. monocytogenes* can reproduce at refrigeration temperatures, an initially low number of *L. monocytogenes* in food can replicate to levels that could cause an illness, even in properly stored food.

In the US, the Food Safety and Inspection Service (FSIS) of the US Department of Agriculture (USDA) is in charge of ensuring safe meat, poultry, and pasteurized egg products produced in Federally Inspected Plants (FIP).[11] All other food products and egg products, after they leave FIP, are under the jurisdiction of the Food and Drug Administration (FDA) of the US Department of Health and Human Services (DHHS). The FDA and FSIS have unrestricted enforcement authority to selectively sample and test for *L. monocytogenes*.[9] The federal government performs nearly 7,500 tests for *L. monocytogenes* annually on processed meat and poultry products.[12]

When a plant has reason to believe that the food products already in trade or in consumer channels could be contaminated with *L. monocytogenes*, the plant voluntarily recalls, i.e., removes the product from commerce to prevent the public from consuming adulterated or misbranded food (defined by USDA, FSIS[13]). If FDA and FSIS believe that a food product may be contaminated with *L. monocytogenes*, they can ask the plant to recall the products. All recalls of food related to possible or proven contamination with *L. monocytogenes* are categorized as a Class I recall. Class I recall is defined as a hazardous situation, where there is a reasonable probability that the use of the product will cause serious, adverse health consequences or death.[13,14] Among all foodborne pathogen recalls, *Listeria* is the most common cause of Class I recall.[13,14]

While listeriosis has been considered a foodborne pathogen and a public health issue for many years, concerns about this pathogen and about food contamination with *L. monocytogenes* have increased considerably over the last 4 years. This higher level of concern about *L. monocytogenes* was triggered by a US multi-state human listeriosis outbreak in 1998/99, which affected more than 100 people.[15] However, there are additional reasons for concern about this pathogen. Increasing demand for foods with extended shelf lives,[16] which often allow and possibly favor growth of *L. monocytogenes*, and an increasing consumption of RTE foods in modern US society may provide a heightened likelihood of human exposure to *L. monocytogenes*. In addition, the population segment highly susceptible to listeriosis has increased and is expected to continue to increase.[17] To address these concerns, DHHS and USDA jointly developed an action plan to meet the US President's call for halving the risk of listeriosis by the year 2005,[18] using the incidence of 0.5 cases per 100,000 people from 1997 as a baseline. The presence of *L. monocytogenes* in many environments, combined with its survival and multiplication capabilities, make efforts to reduce human foodborne listeriosis a challenging task. In order to provide safe food for consumers and prevent listeriosis cases and deaths, significant resources are in use in the US. As resources are scarce, they should be optimally allocated, i.e., to give the maximum benefits for the cost. Therefore, apart from being influenced by risk assessment, any change in strategy for controlling foodborne pathogens also should be supported by economic analysis. In this article, we explore the concept of an economic optimum of food safety measures using *L. monocytogenes* as an example.

The primary objective of this study was to evaluate published literature on the cost and benefit of food safety measures. The second objective was to estimate the costs and benefits obtained by different methods of analysis (e.g., willingness-to-pay, event study, cost function) were combined in order to provide both an estimate of the economic impact that *L. monocytogenes* food contamination has on US society and the optimal level of *L. monocytogenes* food safety. The third objective was to construct a template for analysis of economics of other foodborne illnesses by comparing advantages and disadvantages of different methods applied in food safety economics and to determine possible directions in which different methods of analysis can bias the decision making process.

COSTS AND BENEFITS OF FOOD SAFETY MEASURES

The concept of food safety encompasses many diverse elements. Safe food can be defined as food free from toxins,

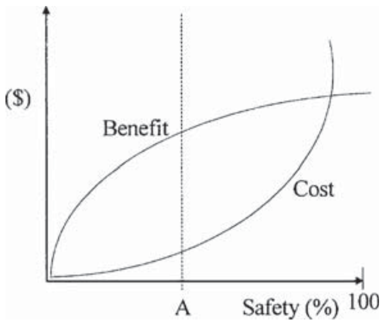

Figure 1 Cost and benefit curves and the optimal level of food safety.

pesticides, chemical and physical contaminants, and microbiological pathogens that can cause illness.[19] This article is concerned only with food safety related to microbiological pathogens, although the principles we apply are valid for other aspects of food safety. In this study, the level of food safety achieved by a specific pathogen control program is assumed to be a complement of the corresponding risk of becoming sick in a year.

From an economic point of view, food safety is a food quality attribute that costs money. Although society benefits from greater food safety, the benefit (prevented losses) is believed to increase at an ever-decreasing rate as increasing levels of food safety are reached (depicted in Figure 1). In contrast, the cost of producing safe food is believed to increase at an ever-increasing rate as food safety increases, also depicted in Figure 1. At any level of safety, the benefit may be greater than the cost. However, that does not imply that safety should be increased, because what matters are marginal changes of costs and benefits. As safety increases, there is a point (depicted as point A in Figure 1) where the benefit over cost of control measures is maximized. If food safety were to be increased beyond point A, the incremental increase in cost would be greater then the incremental increase in benefit. This economic optimum is where marginal benefit is equal to marginal cost; this is depicted in Figure 2 at point A, where marginal benefit and marginal cost curves intersect. It should be noted that this economic optimum is not necessarily socially or even politically acceptable. In this article, we considered only the economic aspects of food safety.

The optimum food safety level is a static equilibrium that may change each period for a number of reasons. Higher incomes can shift the marginal benefit curve upward, because consumers demand higher quality food, including safer food. On the other hand, the marginal cost curve might shift downward because of technological change or new knowledge (e.g., if only certain *L. monocytogenes* strains can cause listeriosis, there should be fewer recalls of food products).

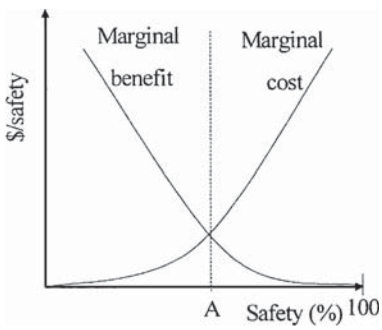

Figure 2 Market equilibrium determination of food safety.

A perfectly competitive and well informed market does not require government intervention to induce the optimal level of food safety. This is because the consumer equates the marginal benefit of each food product to its price, and the competitive firm equates marginal cost to the price.[20] When the supply and demand for each food product clear at a given price, the marginal benefit also is equal to the marginal cost. The appropriate role for the government in this case is to verify the producer's claims on hazard content—not to regulate the level of food safety.[20] In an imperfect market, where neither the producer/supplier nor the consumers are aware of food pathogen hazards, government policies will signal the health effects of substances in food to consumers. Nevertheless, even in a perfectly informed market, consumers may have a subjective belief about the hazard content of the risky food, and they may stick to their belief and be slow in adjusting to new information.[20]

The food industry and the government carry the cost of food safety, while the benefit is reflected in consumers' public health. When analyzing food safety, we should keep in mind the interdependence between the cost and the benefit of food safety, the concept of socially optimal food safety level and the role of government in inducing it. Benefits of a control program should not be evaluated without estimating the change they create in costs of targeted food safety level and vice versa. Ideally, we want to estimate the entire benefit and cost curves, because that will give us the best understanding of the economic optimum of food safety level for a foodborne pathogen. However, the approaches generally used will only identify one, or at best, a few points on each curve. That point is usually at the current level of observed food safety. One point would not even be that much of a limitation, if we knew the slope of the curve at that point, we could get at least a local approximation of the curve. In the next section, we discuss the usefulness of various methods for estimating data points on cost and benefit curves for foodborne diseases.

Benefits

Benefits are reduced losses related to illnesses and deaths prevented by the control program under analysis. There are 5 approaches developed for evaluating policy that affects health and safety. These are cost of illness (COI), willingness to pay (WTP), cost-effectiveness analysis, risk-risk analysis, and health-health analysis.[21] Only the COI and WTP approaches use dollars to measure benefits and are discussed below.

Cost of Illness Approach

The COI approach computes the dollars spent on medical expenses and the dollars of employment compensation that are

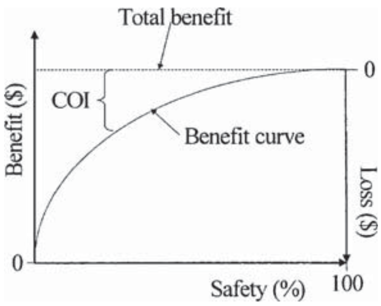

Figure 3 Cost of illness method for estimating benefit of control policy.

forgone as a result of illnesses or premature deaths. If these losses could be eliminated, society would benefit. The COI computes the distance between the benefit curve and the absolute benefit, which would occur if food were 100% safe, as depicted in Figure 3. Thus, the COI method does not estimate the height of the benefit curve, but rather the distance from the benefit curve at the observed level of safety to the benefit level, if food were 100% safe. A limitation of the COI is that it only estimates one point (per observation period) and, therefore, is not able to provide the slope of the curve, unless we assume the benefit curve is linear from the current to the 100% safe point. Knowing the slope of the benefit curve is essential in order to construct the marginal benefit curve to determine the optimal level of food safety. Another issue with the COI is that it does not incorporate the effort to avoid the disease or the discomfort suffered by the disease. Therefore, the estimate obtained from the COI is an underestimation of total benefits related to the foodborne pathogen control.

Driven by financial needs and sometimes by company regulations regarding absence from work due to an illness, people tend to go to work not feeling well. Also, an illness might develop gradually while people are already at work. It is logical to assume that these people do not work as productively as they would if healthy. In a study on productivity decreases related to absence from work due to illness, Brouwer et al.[22] estimated productivity losses before and after work absence from various causes. Because listeriosis can develop symptoms/situations similar to those represented in the survey conducted in this study (influenza-like type symptoms, headache, stomach/intestine problems, and illness of family members), the results of this study are relevant for listeriosis. Analysis of the survey results demonstrated that absence from work contributed 86.3% in total productivity losses among employees who were absent from work due to illness. The rest, 13.7%, was attributable to lost productivity before and after absence from work. This additional loss should be taken into account if the productivity losses due to foodborne illness are based on the value of forgone or lost wages.

Kuchler and Golan[21] state 3 disadvantages of the COI method. Primarily, the basis of COI's theoretical legitimacy is the rather weak assumption that national income is a valid measure of societal welfare. COI equates the value of a life with forgone wages (higher paid members of society are assigned higher values of life). Secondly, COI is not always a good measure of disease severity, because COI estimates are influenced by a number of factors other than disease severity, including the current distribution of income, education, employment skills, technological constraints to disease treatment, sick-leave policies, and health insurance systems (both private and public). As a result, COI estimates often move in the opposite direction from disease severity measures. Finally, direct medical expenses are often difficult to assess accurately because of the intricacies of insurance arrangements; human capital costs are equally difficult to ascertain because of the various forms of compensation that are available to employees. However, despite COI's weakness as a measure of welfare or disease severity, COI does provide a measure of the economic impact of illness.

Willingness to Pay Approach

WTP measures the resources that individuals are willing and able to give up for a reduction in the probability of encountering a hazard that will compromise their heath. It is generally implemented by surveying people as to what they would be willing to pay for an increase in food safety from some current level of safety. Questions can be constructed to generate many points (each for a different level of food safety) on the benefit curve, providing an estimate of curvature. In addition, if the question is cast in terms of how much the consumers would pay for an increase in food safety of some amount, then we have a direct estimate of the marginal benefit. The WTP is the true benefit curve. In contrast to the COI approach, WTP accounts for potential discomfort suffered by the disease and the effort to avoid the disease. The COI method underestimates the benefits of an increase in food safety, because it excludes costs of averting behavior and discomfort costs associated with greater food safety (depicted in Figure 4). Because of this exclusion bias, the COI benefit curve appears to be higher than the WTP curve. As a result, with any increase in food safety the marginal benefit from WTP is larger than the marginal benefit from the COI estimate. However, once 100% safety is reached, the COI benefit and the WTP benefit should be identical, because there are no avoidance and discomfort costs.

Although the WTP method is more comprehensive than COI, it also has disadvantages.[21] WTP reflects individual preferences

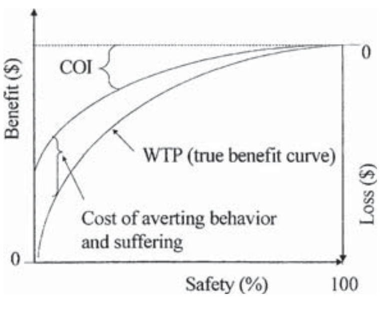

Figure 4 The relation between COI and WTP estimates of benefits of a control policy.

for risk reduction, where the demand for risk reduction is derived from expected health benefits. Because these quantities account only for expected (ex-ante) and not for observed benefits at the moment of choice, they are not equivalent to realized damages. Secondly, WTP reflects the observation that individual preferences are unique and individual demands for risk reduction vary. However, because health and safety cost money, income differences, rather than preferences, will explain some of the variance in WTP estimates. Therefore, when benefits are calculated by WTP, policies may be guided away from programs that save poorer lives and toward programs that save wealthier lives. Furthermore, empirical estimates of WTP have proved sensitive to the characteristics of the study population, the level of risk and the type of risk. In practice, regulatory agencies that have adopted the WTP approach have generally adopted a single value for lives saved, where the values have been derived from compensating wage studies.[21] Agencies apply this value to every health risk, regardless of the population likely to receive program benefits, the type of risk that might be mitigated, or the level of risk mitigated. Nevertheless, in spite of these limitations, WTP valuations represent a consistent and faithful application of the principles of applied welfare economics. WTP measures provide the best estimate of individual welfare available to economists.

The WTP method requires conducting a survey in which respondents are asked to choose between two risks and decide how much they are willing to pay for the reduction of risk to their health.[21] A simplified pattern of survey questions could be to ask respondents how much they would be willing to pay for a food product, considering the fact that the food could be contaminated with a pathogen at some probability level. They are then asked how much they would be willing to pay for a food with a treatment that destroys that pathogen at some stated probability. The questionnaire could have open-ended questions or a discrete choice format, requiring acceptance or rejection of the reduced risk at a given cost. However, as stated by Fox et al.,[23] discrete choice questions correspond more closely to real world situations because, for the majority of food purchases, the decision is either to buy or not to buy at the posted price. Respondents to the survey are often recruited from a student population at a low cost. However, that might be a source of bias, since willingness to pay for a particular food under specific risk assumptions is very individual. Moreover, willingness to pay is restricted by the ability to pay, i.e., how much a particular person is able to spend on safer food. Students, usually young people, might be characteristically blasé about food poisoning risks; they often think they are immune to any risk. Additionally, their financial situation might force them to be less averse to risk compared to the rest of population. On the other hand, students might have a better overall knowledge of foodborne pathogen related issues. Therefore, selection bias introduced by respondents should be taken into account when designing a survey and analyzing survey results. The other problem with surveys is that respondents know they are evaluating a hypothetical scenario, and as affirmed by Fox et al.,[23] the absence of market discipline applied in the real world by budget constraints and the availability of substitutes make their responses questionable.

Recently, economists have developed experimental auction market methods that can serve as useful complements to surveys estimating WTP. Compared to surveys, experimental auction markets use real money and real goods to create scenarios in which the participants give exclusive attention to the task under evaluation. This experiment might have several rounds of bidding for the same food product, which gives an opportunity to introduce additional information about the product being valued (e.g., a treatment that destroys or reduces *L. monocytogenes* in food) and to measure the effect of that information on the evaluation by participants. Nevertheless, the experimental method has disadvantages too, mainly higher costs per participant, the experimental method often costs double that of a survey.[23] Although results of experimental auction market methods have a more realistic flavor compared to surveys, they cannot be used solely as estimates of willingness to pay to avoid disease. They can and should be used as a valuable support of survey study results.

Costs

The food industry and the government incur the costs of a food safety control policy. The quantification of governmental costs was beyond the scope of this study. According to Feigenbaum,[24] total quality costs for an industry can be divided into failure costs (cost of recalled and destroyed products), appraisal costs (sampling and testing), and prevention costs (cost to reduce contamination), which are all depicted in Figure 5 as a function of food safety. Appraisal and prevention costs both increase, as safety increases, so they can be combined. Failure cost is not independent of prevention cost. As expenditures on prevention increase, it would be expected that failure costs would decrease. Likewise, an increase in appraisal costs, for example, due to testing, may decrease failure costs. That is because testing should find potential contamination sources (food plant environment, raw material) before they lead to finished product contamination. Similarly, changes in food technology should shift the cost curves. With improved safety technology, the failure cost curve will shift downward, because fewer products will need to be recalled. Figure 6 shows this as a parallel shift, although the shift may not always be parallel. This is an important consideration,

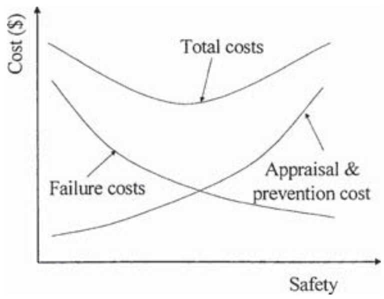

Figure 5 Total industry costs of food safety.

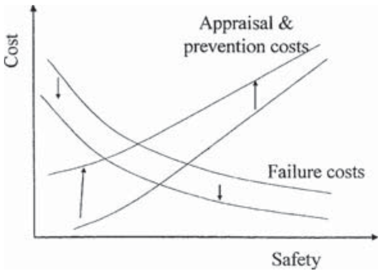

Figure 6 Decrease in failure costs due to the increase in appraisal and prevention costs.

because a parallel shift does not change the slope of marginal cost and then the optimal safety level. Appraisal and prevention cost should shift upward, but may be in a clockwise manner as safety technology increases, as depicted in Figure 6. The clockwise shift (holding failure shift parallel) means that the marginal cost curve falls at any level of safety, and the new intersection of marginal benefit and marginal cost results in a higher optimal level of food safety. In Figure 7, this is depicted as a move from point A to A'. However, if the failure cost curve shifts downward in a nonparallel way, the slope of the total cost curve changes; the new intersection point could be in either the direction of a lower or higher optimal level of food safety.

Three methods for estimating the costs of a control program related to the food industry can be applied. They are an econometric cost function for production plants, an event study method, and the direct accounting cost at a specific level of food safety.

Econometric Cost Function for Production Plants

Estimating the cost function (cost of production) for a production plant, where food safety is included as a cost determinant, requires assessing the cost of a foodborne pathogen control program. Although we can sum or aggregate estimates for many firms, we usually estimate an aggregate cost function for the industry. Antle[25] demonstrated that product safety affects productive efficiency and costs, i.e., that cost of production is increasing with product quality. The cost function approach, suggested by Antle,[25] directly estimates the total cost curve (see Figure 5). The challenge is to quantify the level of food safety, and then

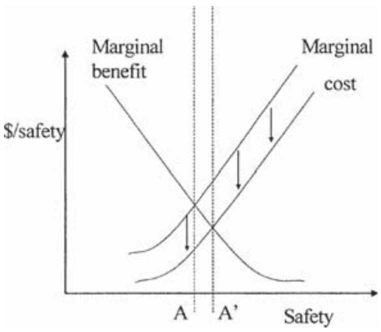

Figure 7 Change of optimal level of food safety due to change in marginal cost.

enter that as a variable in the cost function. However, Antle[25] did not quantify cost of safety in his data set. Instead, he used an indirect procedure from observed food prices, because consumers pay more for safe food. This hedonic approach must be used if the food safety level cannot be quantified.

"Event Study" Method

The "event study" approach estimates the impact of a food safety recall on the firm's net worth, which is the discounted net income of the firm. Future profitability may decrease because of increased costs due to recalls of *L. monocytogenes* contaminated food, additional costs to ensure future safety, as well as lost future sales. There are a number of factors to consider when using this approach. First, if the analysis of total costs and benefits is to be expressed per annum, the estimate derived from the event study must be annualized, since it includes both current and future net income. Second, the "event study" approach counts both income and cost where income is often lost sales. The limitation of the event study approach is that the losses a firm faces may not consist entirely of societal costs. The total cost or loss of one firm may result in a market gain for another firm with little or no social cost, or at least social cost less than the equity loss by a firm. If other firms make up for those lost sales, then that income should be removed from the analysis, although consumers do suffer welfare loss if they can no longer eat, for instance, their favorite brand of hot dog. To quantify the impact of a recall on shareholder wealth, Thomsen and McKenzie[26] applied the event study method using daily security prices of food companies assuming stock market efficiency. If meat and poultry recalls do result in substantial firm costs or adversely affect the future earnings of food companies, the impact of the recall will be reflected in adverse stock price movements.

The Costs at a Specific Level of Food Safety

The third approach we can use is to compute the food industry costs at a specific level of food safety. Actually, this approach is the counterpart to COI, which estimates the public health losses at a specific level of food safety. This method accounts for the cost of products' sampling/testing, product recalls, and destroying products. Note that the value of destroyed products is a cost to the producer, because products have to be replaced from the producer's resources. The limitation of this method is the difficulty of obtaining the prevention costs. Therefore, this method underestimates the total cost of a specific level of food safety.

COSTS AND BENFITS OF L. MONOCYTOGENES *FOOD SAFETY MEASURES*

Benefits of L. Monocytogenes *Food Safety Measures*

To estimate public health benefits of a *L. monocytogenes* control policy, the COI and the WTP methods can be applied. The

COI method counts medical expenses attributable to all cases of listeriosis and forgone wages if people are unable to work. For that, all cases of listeriosis should be counted. In a study by Buzby et al.,[27] updated in ERS/USDA Briefing Room,[28] listeriosis cases were categorized by those who did not seek medical care, those who visited physicians but were not hospitalized, and those who were hospitalized. However, in analysis, they considered only hospitalization cases, because only these data were available. Hospitalized cases were divided into categories by those who recovered and those who died. Each group that recovered or died was categorized into maternal cases, fetal/newborn, and other adult cases. Furthermore, other adult cases were categorized as to whether they developed moderate illness or severe illness. Only some of the fetal/newborn cases developed chronic disease, which resulted in mild, moderate, or severe disability. Among fetal/newborn cases that survived, only those that developed chronic disability were counted as productivity losses. For the total of 2,298 acute and chronic cases Buzby et al.,[27] updated in ERS/USDA Briefing Room,[28] estimated \$.072 billion and \$2.261 billion of annual medical cost and productivity/premature death loss, respectively, or in total, \$2.333 billion. This estimate represents a point on the benefit curve that corresponds to the current level of food safety and the distance to the total benefit line (Figure 3). Because we had the point estimate only for the current food safety level, we could not estimate the slope of this potentially nonlinear benefit curve. Therefore, we were forced to assume a linear benefit line that goes through the estimated point for the current safety level and the point that corresponds to 100% food safety and total benefit. Next, to estimate the marginal benefit, the COI benefit estimate was divided by the annual number of listeriosis cases in the US of 2,493[2], used as a measure of the level of food safety achieved by the current *L. monocytogenes* control program. Marginal benefit is estimated to be constant at approximately \$.9 million per prevented listeriosis case (Table 1).

It should be noted that the estimates obtained from the COI method underestimate the total loss related to listeriosis in several ways. These estimates do not include medical expenses related to mild cases of listeriosis that did not warrant a visit to the physician, or the visit to the physician did not result in hospitalization. Losses of productivity before and after absence from work are not included. Also, neither the discomfort that people with listeriosis suffer, nor the effort spent to avoid the disease, was included.

Table 1 Estimates of the annual and marginal benefit of *L. monocytogenes* control

Method	Annual benefit (billion (\$))	Marginal benefit per Prevented Case (million(\$))	Source
COI	2.333	0.9	-Buzby et al.[27] and ERS/USDA Briefing Room[28]
WTP	11–22	4.4–8.8	-Hayes et al.[29] -FDA/USDA/CDC[15]

The WTP method allows for the accounting of all components missing from the COI method. In order to estimate how much people are willing to pay for food safety, Hayes et al.[29] applied an experimental auction market method, considering five foodborne pathogens: *Campylobacter, Salmonella, Staphylococcus aureus, Trichinella spiralis*, and *Clostridium perfringens*. Based on mean bid estimates, the average subject in their study would be willing to pay between a 15% to 30% premium per meal to reduce the objective risk of foodborne illness to 1 in 100 million (this ranged across studied pathogens from 1 in 125,000 to 1 in 25 million). The authors stated that, despite all the efforts to glean pathogen-specific information, results suggested that, regardless of stated probability and severity, the average participant's WTP for safer food is an indicator of general food safety preferences. Because the results presented in this study are not pathogen specific, we assume that they could be used for any foodborne pathogen, including *L. monocytogenes*. To estimate how much more people would be willing to pay for safer RTE food, we need the estimation of the current expenditure for RTE food. Because this estimate was unavailable, we utilized the data used by the FDA/USDA/CDC,[15] on the annual number of servings of different RTE food categories consumed in the US. The 50th percentile of serving size for each of these food categories was multiplied with its market price, obtained from the Bureau of Labor Statistics Data (BLS) of the US Department of Labor.[30] Calculated annual expenditure for RTE food was \$76 billion. RTE food consumption, reported in FDA/USDA/CDC,[15] is restricted to the majority of RTE food that has been historically associated with contamination by *L. monocytogenes*. Furthermore, only some market prices of RTE food products were available from BLS. For all unavailable prices, we calculated and used an average of those that were available. Therefore, our estimate of annual expenditure for RTE food is imprecise, but it is the best we could obtain from available data. From expenditures on RTE food, we calculated that people would be willing to pay \$11 to \$22 billion more for food with 1/100 million risk of food poisoning annually. This is the range that represents the possible distance between the benefit curve and the total benefit line at the current level of food safety (Figure 4). Because we know only one point on the benefit curve, we could not estimate the slope of this possible nonlinear curve. Therefore, we assumed a linear benefit line to 100% food safety and total benefit. As a measure of the level of food safety achieved by the current *L. monocytogenes* control program, we used the number of listeriosis cases in the US per year.[2] From there, constant marginal benefits were estimated that ranged from \$4.4 to \$8.8 million per prevented listeriosis case (Table 1).

Food Industry Costs of L. Monocytogenes *Food Safety Measures*

As a result of the regulatory attention that RTE food products receive based on the "zero tolerance" policy for the presence of *L. monocytogenes*, a significant number of recalls have plagued the food industry.[31] The information on product recall may affect consumer demand for the product involved, which may lead to millions of dollars of lost sales, as well as loss of brand equity. Furthermore, consumer demand for a product similar to the one recalled could decrease or increase, depending on whether or not consumers believe that these similar products are safe. In addition, Roberts and Foegeding[32] included plant closings and cleanup after recall, product liability costs, and insurance administration costs. Facing huge losses related to a possible recall, manufacturers of RTE food products fear the consequences of *L. monocytogenes* in their products. Therefore, they attempt to eliminate the pathogen from the production environment. This is done through comprehensive cleaning and sanitizing, separation of raw material and processed product areas, control of employee hygiene and movement in production areas, and environment and food product microbiological testing.[31] These measures require extra work, cleaning, disinfection, alteration of production procedures, and education, which all cost money. Some of these costs are reflected in changing stock market prices of the food industry.[26] The "event study" method allows measurement of the impact that recalls have on food-production firm equity values. Thomsen and McKenzie[26] studied the impact of a recall on shareholder wealth using daily security prices of food companies. Their results, based on 479 recalls from 1982 to 1998, suggest that, on average, a Class I recall results in a 1.5–3% reduction in shareholder wealth. The predominant reason for recalls in that study was *L. monocytogenes* contamination. It is reasonable to assume that *L. monocytogenes* recalls do not differ from other food borne pathogen Class I recalls, and therefore, the results of Thomsen's and McKenzie's[26] study are applicable to *L. monocytogenes* recalls. To assign a dollar value to the reported estimate of reduction in shareholder wealth, we should multiply the 1.5% to 3% range with an average market capitalization value of all firms, or at least a random sample of firms, involved in the study. Because this information was unavailable to us, we used the average firm market capitalization value of the 10 largest food companies in the year 2002. The estimated average firm market capitalization value of $15.9 billion was based on the following companies: Kraft Food Inc., General Mills, Sara Lee Corp., Kellogg Co., Heinz, ConAgra Inc., Wrigley Jr. Co., Campbell Soup Co., Hershey Foods Corp., and Archer Daniels Midland Co.[33] From there, we estimated that the lost equity value to any of these firms because of a *L. monocytogenes* recall may be as high as $0.24 to $0.48 billion. Based on Thomsen and McKenzie,[26] there were 89 recalls due to *L. monocytogenes* contamination from 1982 to 1998, or 5 recalls annually. Assuming an efficient capital market and a constant number of annual recalls in the industry, the reduction in equity value is the annualized costs of the recalls in present dollars, although the actual accounting cost impact in the future may be much greater than the current value of those discounted income streams. Therefore, the annual cost of all recalls related to *L. monocytogenes* may be as high as $1.2 billion to $2.4 billion (see Table 2). Within this range is a point on the cost curve that corresponds to the current level of food safety (Figure 5). To be able to estimate a slope of the cost curve, we assumed a linear cost line to 100% food safety and maximal cost. The annual estimate of the number of listeriosis cases in the US of 2,493[2] was used as a measure of the level of food safety achieved by the current *L. monocytogenes* control program. Estimated marginal cost per each prevented case of listeriosis ranged from $.5 million to $1 million.

Table 2 Estimates of the annual and marginal cost of *L. monocytogenes* control

Method	Annual cost (billion ($))	Marginal cost per Prevented Case (million ($))	Source
Event study	1.2–2.4	0.5–1	-Thomsen and McKenzie [26] -Yahoo! Finance[33]
Cost at a specific level of food safety	0.011–0.021	0.004–0.008	-Antle [25] -FSIS [34] -FDA [35]

It should be noted that the annual cost estimate could be biased in any direction. For example, this annual cost could be used as an upper limit estimate of an annual cost of all *L. monocytogenes* recalls, as it is based on the cost per recall for the 10 largest food companies. However, more recently reported annual numbers of *L. monocytogenes* recalls[13,14] are much larger than the 5 recalls used for estimating the total annual cost in this example. As discussed below, 70 recalls due to *L. monocytogenes* were documented for the US in the year 2000 alone. Furthermore, in their study, Thomsen and McKenzie accounted only for recalls of meat and poultry food products reported by FSIS. Also, governmental costs related to the control of *L. monocytogenes* are excluded from this estimate.

While some food production plants lose because of *L. monocytogenes* problems, other plants may gain because of an increase in consumer demand for their products. Because the total consumption of all kinds of food products within the US remains stable, the only real loss due to *L. monocytogenes* for US industry might be the cost of preventing contamination and appraisal costs, and the loss of discharged products with associated discharge costs when a product is found to be contaminated (failure costs). However, the consumer might want to eat a hot dog of a particular brand, but because of an outbreak of *L. monocytogenes*, must switch to another brand of hot dogs or even a different type of food product, e.g., tofu. Therefore, in terms of cost and nutrition value, the consumers' welfare might be affected by switching to a different brand and/or type of food product. These costs are difficult to quantify and are, thus, generally not included in food safety cost-benefit analyses.

We also may look at the cost of a specific level of food safety, such as the current recall policy of identified contaminated food. To account for the cost of that food safety level, we have to combine the production cost of recalled products and all the costs related to the process of discharging (e.g., transport, storage while waiting for test results and cost of discharging). To count all recalls reported in the year 2000, we combined the meat and poultry recalls reported by the FSIS[34] with recalls of other food products reported by the FDA.[35] Although there were 70 recalls in the year 2000, the amount of recalled products was known for 65 (for 5 the amount of recalled product was unknown); these will be considered further in the analysis. In total, 8,257,000 kg of food were recalled, or on average, 118,000 kg per recall. It should be noted that 35 recalls, regulated by FSIS, accounted for 99% of total recalled quantity, or 8,202,000 kg of meat and poultry products. Although the FDA recalls were similarly frequent (40 recalls in the year 2000), they were much smaller in terms of the amount of product recalled. The question is whether the unit production cost for a product recalled by the FDA (e.g., the price of a sandwich) differs from the unit cost of a product recalled by the FSIS (e.g., a kilo of poultry product). Food producers keep production costs confidential. However, according to Antle,[25] the production cost in poultry, beef, and pork slaughterhouses and processing plants is between $1.32 and $2.54 per kg. Lacking specific information for RTE product production costs, we used these estimates to calculate the annual cost of *L monocytogenes* recalls. The estimated total cost of *L. monocytogenes* recalls was $.011 billion to $.021 billion (or $.16 to $.3 million per recall) in the year 2000 (see Table 2). Within this range is the point on the cost curve corresponding to the current level of food safety (Figure 5). Again, to be able to estimate a slope of the cost curve, we assumed a linear cost line to 100% food safety and maximal cost. The number of listeriosis cases in the US per year[2] was used as a measure of the current level of food safety. Estimated marginal cost per prevented case of listeriosis ranged from $.004 million to .008 million.

An econometric cost function study by Antle[25] developed a model of quality differentiated production with quality control; it estimated the possible costs of new food safety regulations (Hazard Analysis Critical Control Points—HACCP) being implemented by the USDA. For a 90% prior safety level (i.e., 10% of products contaminated with any foodborne pathogen), Antle[25] reported that HACCP implementation might result in an increase of a total variable cost of .45 to 4.08 cents per kg. However, the value of 10% used in this calculation for product contamination with foodborne pathogens is higher than that found for *L. monocytogenes* contamination of RTE products.[15] An additional difficulty of using this estimate for the derivation of the total costs attributable to *L. monocytogenes* control is that HACCP measures increase food safety for all foodborne pathogens, including *L. monocytogenes*. However, only a portion of the total HACCP cost is caused by *L. monocytogenes*. It is impossible to estimate either how big that cost is or how effective implemented measures are in eliminating *L. monocytogenes* from food. In addition, costs of some *L. monocytogenes* control strategies implemented by processing plants may not be HACCP related.

The Impact of Governmental Costs on Total Cost of **L. Monocytogenes** *Measures*

Government costs are believed to be an increasing function of food safety. The more inspectors take samples and test the food, the greater the cost. However, this establishes a greater level of food safety. Marginal government cost should be compared to the marginal benefit function to give the optimum government expenditure for food safety. The costs borne by the government certainly have a significant share in the total societal costs of *L. monocytogenes* food safety. However, the challenge with the government costs related to *L. monocytogenes* control is the difficulty of estimating how much of the total employees' time (wages) and/or resources is attributable to *L. monocytogenes* food safety. Therefore, we omitted these costs from our study, keeping in mind that our estimate of the true total cost related to *L. monocytogenes* control in the US will be underestimated.

DISCUSSION

Although the problem of *L. monocytogenes* control commences at the pre-harvest level, contamination is likely to occur at any later stage of the food production chain. Our study focuses on the post-harvest level of food production, because interventions at that stage are closer to food consumption and have a stronger effect on *L. monocytogenes* contamination of RTE food. *L. monocytogenes* is ubiquitous and can enter the production chain anywhere. It is, therefore, difficult to control. Because control costs money, the question is which level of food safety is optimal. In this article, we considered only the economic optimum of food safety, which is not necessarily socially or politically acceptable.

To find the optimal level of *L. monocytogenes* food safety, ideally, we need to know the entire industry cost and public health benefit curves. Unfortunately, most estimation procedures provide only one point estimate. To overcome the lack of points on cost and benefit curves, we were forced to assume linearity of benefit and cost lines. The COI method of calculating annual public health benefits of the current *L. monocytogenes* control program gave an estimate of $2.333 billion[27,28] (Table 1). This estimate still underestimates the total benefits of the current *L. monocytogenes* program, mainly because it does not take into account discomfort caused by listeriosis and the effort people are willing to make to avoid the disease. According to Hayes *et al.*,[29] an average person is willing to pay 15–30% more for a meal with 1:100 million chance, compared to objective risk of food poisoning that ranges from 1:125,000 to 1:25 million. From the estimate of annual expenditures on RTE food of $76 billion (based on BLS[30] and FDA/USDA/CDC[15]), we calculated that people would be willing to pay $11 to $22 billion more for food that has an associated risk of *L. monocytogenes* food poisoning of 1:100 million (Table 1), which is considerably (5–10×) more than the $2.333 billion COI estimate. This high WTP estimate may appear to be implausible, but in a review of available information on the extent of foodborne illness in the US by the US General Accounting Office, the WTP estimate for 1993 ($1.5 to $3.0 billion) was 15× larger than the COI estimate for 1992 ($.1 to $.2 billion).[36] Although the COI method gives an underestimation of the true costs and losses of listeriosis, it is popular because it is easy to perform, and the reduction of listeriosis cases and deaths can be compared between different control programs. WTP gives a more accurate estimate, as it accounts for all factors contributing to public health losses from *L. monocytogenes*.

For food industry costs, the "event study" method[26] of the impact of a recall on shareholder wealth demonstrated that any Class I recall (including a *L. monocytogenes* recall) results in a 1.5 to 3% reduction in shareholder wealth. Multiplying these estimates with an average firm equity value of the 10 largest US food companies[33] gives a value of annual recall cost of \$.24 billion to \$.48 billion, or \$1.2 billion to \$2.4 billion annually (see Table 2). Although this method did not result in an accurate estimate of food industry cost due to *L. monocytogenes* recalls (as previously discussed in the section labeled "Food Industry Costs of *L. monocytogenes* Food Safety Measures"), it still has a value. It pointed out the gaps in the current knowledge on the economics of *L. monocytogenes* food safety, which may direct future research in the area of costs and benefits related to *L. monocytogenes* food safety measures. Share market disturbances caused by food recalls are not very precise measures of recall costs, as they depend on timing and the type of information that stock owners receive. Therefore, an estimate of direct costs per recall that results from a specific level of food safety might also be useful. Due to all *L. monocytogenes* recalls in the year 2000, products ranging in value from \$.011 billion to \$.021 billion were destroyed (see Table 2). In terms of total food industry costs, the direct cost of a recall has limitations, as it does not take into account the cost of discharging, preventing, and monitoring measures applied by the production plant to avert *L. monocytogenes* food contamination. A method that can account for total costs of food safety measures is a cost function method. Antle[25] estimated that measures implemented by HACCP cause an increase in total variable cost of .45 to 4.08 cents per kg of product. However, HACCP aims to control all foodborne pathogens in food, including *L. monocytogenes*; it is impossible to isolate the portion of total HACCP costs relevant to *L. monocytogenes*. The difficulty in separating total costs related to *L. monocytogenes* from those attributable to other foodborne pathogens leaves two available estimates for food industry costs of *L. monocytogenes*. These are an estimate of the change in shareholder wealth as a consequence of a *L. monocytogenes* recall, and an estimate of the direct cost of a recall. Despite the large market capitalization value (based on market capitalization value of the 10 largest food producers) used for estimating the change in shareholder wealth as a consequence of a *L. monocytogenes* recall, the range that these two estimates probably represent is the lower bound estimate of total food industry costs related to *L. monocytogenes*. Furthermore, this range is an underestimation of total societal costs, because it does not account for the important costs borne by the government. The upper bond of total societal cost due to *L. monocytogenes* control and the slope of marginal cost remain unknown.

Estimated marginal benefit exceeds estimated marginal cost, which leads to the conclusion that more food safety measures, i.e., a higher food safety level, are warranted. However, we have no knowledge concerning how much higher food safety level would be optimal, because we were forced to assume linear marginal curves from the current level of food safety. Interestingly, the upper bound estimate of marginal cost overlaps with the COI estimate of marginal benefit. The fact that our estimates of cost underestimate the true cost indicates that an even larger overlap between the marginal benefit and cost is possible, which could be interpreted in favor of under investment in food safety. However, it should be recognized that the COI method strongly underestimates the benefit of *L. monocytogenes* food safety measures.

To the best of our knowledge, our study is the first attempt at combining all the available knowledge for the costs and benefits of *L. monocytogenes* control. Also, we are not aware of any study that has tried to determine the economic optimum of *L. monocytogenes* food safety measures on US society. Estimates of the total societal cost and benefit that were extrapolated from available literature on *L. monocytogenes* did not provide us with enough information to construct the cost and the benefit curves. Therefore, the level of *L. monocytogenes* food safety that would be optimal for US society, from an economic point of view, cannot be determined. The gaps in the knowledge on the costs and benefits of *L. monocytogenes* food safety control identified in this study might serve as a guide for future economic analysis and will help in shaping rational approaches to define and assure a safe and affordable food supply.

CONCLUSIONS

The biology of the pathogen *L. monocytogenes* makes the goal of total *L. monocytogenes* elimination from food unrealistic. The level of *L. monocytogenes* food safety we should aim for will be the one that the consumers will be willing to pay, equated to the incremental cost of providing that level of safety. Determining the optimal level of food safety requires estimating the cost and benefit curves and then determining the marginal increase in benefits and costs for various increases in safety. For an economic optimum of food safety level, marginal benefit should equate to marginal cost. In addition, social and political issues obviously need to be considered when determining an acceptable level of food safety.

We reviewed available published literature on the economics of *L. monocytogenes* food safety measures and critically analyzed reported results and the methods applied to estimate the costs and losses related to *L. monocytogenes*. Our findings are structured to serve as a future reference for the economic analysis of both *L. monocytogenes* and other foodborne pathogens. To the best of our knowledge, a systematic economic analysis of the total societal costs and losses and estimation of an optimal level of food safety has not been conducted for *L. monocytogenes*, or for any other foodborne pathogen to date. Therefore, we believe that our work contributes to the overall knowledge of the economics of foodborne pathogens and has a special value in making decisions and plans related to future *L. monocytogenes* control and research.

Our study demonstrates how incomplete the current knowledge is regarding the specific points and slopes of both the cost and benefit curves of food safety. Therefore, future studies of the economics of *L. monocytogenes* should be designed to provide estimates of total societal costs and benefits. From there, the level of food safety that is optimal for US society can be determined. The understanding of the optimal food safety level will contribute to designing an alternative *L. monocytogenes* control program that would be the most effective and economic, but at the same time, acceptable for US society.

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