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Policy analysts in the United States and other countries have made significant progress toward developing an integrated, risk-based approach to assuring food safety. Food safety agencies have adopted risk-based regulatory approaches, principally Hazard Analysis Critical Control Points (HAACP) systems, and have made significant efforts to coordinate policy development. However, both food safety agencies and private parties (companies and consumers) would be able to focus their risk management efforts more effectively and efficiently if they had better knowledge of how economic behavior influences risk levels across the food system. Integrating this knowledge with scientific information on food safety hazards allows an improved ability to understand how interventions intended to improve food safety will be implemented and to evaluate their ultimate effectiveness.

The economic assessment of interventions and intervention strategies is a critical step in setting priorities related to reducing the public health impact of foodborne illness. Understanding the relative effectiveness for risk reduction of the available options is essential to this assessment. In public risk management decision making, the goal of intervention assessment is often to support ranking of the relative effectiveness of available interventions in reducing the public health burden related to the hazards under review. In private decision making, a range of legal, regulatory, and business needs may also motivate intervention assessments.

Resources available to control food safety hazards are limited and compete with other potential uses. Public policymakers, regulatory agencies, and state and local food safety and health agencies, as well as private firms, face a difficult task in determining the best use of food safety resources. Economic approaches to measuring the impacts of interventions contribute to these decisions by highlighting the full range of factors, including economic incentives and behaviors that affect the risk reduction benefits that will be achieved. They also contribute by quantifying the cost effectiveness and net benefits of interventions.

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Economic measures of food safety interventions address questions that arise in evaluating interventions such as the following:

1. At what points across the farm-to-table continuum could interventions be applied to reduce the risk (and public health impact) of foodborne illness?
2. How effective are available interventions in reducing the risk of illness in terms of measures of adverse health outcomes?
3. What are the costs to government, industry, and consumers of implementing the intervention(s)?
4. Are there supply chain effects (that is, changes in behavior either up or down the supply chain from where the intervention takes place) that will significantly influence the ultimate effectiveness of the interventions being analyzed?
5. What are the cost effectiveness and net benefits associated with different interventions?

A workshop organized by the Food Safety Research Consortium held at the University of Massachusetts Amherst in December 2004 focused on methodological approaches to economic measures of interventions that can be used to evaluate the effectiveness of risk-reducing interventions. These approaches incorporate the technical effectiveness of interventions in reducing risk (e.g., the reduction in product samples with pathogen levels over a tolerance level), the resulting benefits in terms of improvements in public health, and the costs of intervention. In addition, they frequently include modeling of potential supply chain effects resulting from an intervention at a particular point in that chain. For example, lower pathogen loads on food products brought about at the processing level may not translate into improved food safety if those responsible for the distribution and holding of a product are not motivated (compensated) to handle the product properly (e.g., temperature control) through to consumption.

The researchers in the workshop were asked to address the strengths and drawbacks of the methodologies they used, how well the methodologies answer questions about the effectiveness of specific interventions and the overall targeting of intervention resources, and how the research agenda should move forward to improve the usefulness of economic analyses in setting priorities for reducing foodborne illness. The five papers in this special volume of the *Journal* provide leading research that offers insight into the methods, data, and economic approaches that can be used to better understand, measure, and evaluate the impacts of food safety interventions.

McNamara, Miller, Liu, and Barber (pp. 157–172) develop a farm-to-fork stochastic simulation model of *Salmonella* in the pork production and consumption system. Their systems-wide approach and explicit inclusion of uncertainty into a stochastic simulation organize and integrate data on the risk of pathogen contamination and transmission across that system. This approach allows them to address comparative questions about the effectiveness of alternative interventions and controls in reducing foodborne illness. Based on their experience, McNamara et al. discuss the specific approaches and decisions required to account for data with varying levels of rigor and specificity across the pork production and consumption system.

The Dutch government has supported a major effort to reduce campylobacteriosis cases in the Netherlands through the CARMA (*Campylobacter* risk management assessment) project. An important element of this project is the economic analysis of *Campylobacter* control in the Dutch broiler (chicken) meat chain conducted by Mangen, de Wit, and

Havelaar (pp. 173–192). The authors present the methods and findings that are the basis of their approach to comparing the costs and benefits of interventions. They use a risk assessment model of *Campylobacter* infections in the broiler meat chain to evaluate the effectiveness of alternative interventions and estimate the related costs. Estimates of benefits include a reduction in the burden of disease based on epidemiological data and a separate cost-of-illness measure. The resulting cost-utility ratio yields a measure of the relative efficiency of alternative policy options to reduce *Campylobacter* infections. The existence of significant imports and exports in the Dutch broiler sector poses particular challenges for decisions about the choice of interventions and for measuring their effectiveness. For example, counting benefits to consumers both inside and outside the Netherlands makes the cost-utility effectiveness measure of an intervention more favorable, while the existence of imports makes prediction of the health impact of control measures put in place only within the Netherlands difficult. Mangen, de Wit, and Havelaar's development of a generalizable cost-utility ratio allows comparison of interventions and effectiveness across the public health sector.

The lack of available information often limits databased approaches to evaluating food safety interventions. Ollinger and Moore (pp. 193–210) address how researchers can develop the information necessary to measure changes in practices and costs resulting from interventions intended to improve food safety outcomes. They describe and evaluate a major survey effort to develop the data required for assessing industry costs of food safety technologies and controls. A review of empirical approaches and economic models frames the data collection effort in terms of the type of information needed to analyze the impacts of interventions. Based on these identified data requirements, Ollinger and Moore developed the Food Safety Technologies and HACCP Compliance Survey to elicit data from firms on their use of food safety technologies, food safety practices, and costs of HACCP compliance. Ollinger and Moore's experience with survey design and procedures provides useful guidance for related efforts to gather required practice and economic data.

The two remaining articles, one by Nganje, Kaitibie, and Sorin (pp. 211–228) and the other by Tauer, Nightingale, Ivanek, Gröhn, and Wiedmann (pp. 229–243), provide detailed assessments of the cost-effectiveness of food safety interventions at the plant level. Nganje, Kaitibie, and Sorin focus on the firm-level costs and benefits of using specific critical control points within the context of mandatory HACCP adoption. They develop a stochastic optimization framework to determine optimal testing and sampling strategies for *Salmonella* reduction in turkey processing. This approach can be used to highlight the tradeoffs that exist for the firm, and ultimately for regulatory agencies, between stricter tolerance levels and plant-level implementation costs.

Tauer et al. consider the problem of *Listeria monocytogenes* in smoked salmon. They use a multiple equation, dynamic stochastic process model of fish filet slicing and packaging to simulate the production process for a smoked salmon processing plant. This model allows a comparison of trade-offs between reduction in contamination and estimated costs across a range of contamination levels in producing finished products. They find that in the plant studied, the firm's ability to employ desired levels of contamination-reducing strategies and inputs would likely be limited by the relatively small price-premium available in the market for products with reduced contamination levels.

The articles in this special edition make a contribution to an integrated, risk-based approach to assuring food safety through the development of economic measures of interventions. These measures seek to provide a variety of assessments of the overall effectiveness of such interventions. As these articles indicate, the challenges faced in such assessments are many and include the need to integrate understanding of economic and physical relationships that influence, and possibly limit, the ultimate effectiveness of interventions intended to reduce foodborne illness. Development of technical information and data on the effectiveness of interventions often requires close collaboration between researchers and private industry. Economic analysis to support risk-based management decisions may require data on technologies, practices, risk reduction outcomes (benefits), costs, and changes that occur in the supply chain upstream (e.g., input suppliers) or downstream (e.g., at the food service, retail, or consumer levels) from the point or points where the intervention is applied. Better risk management is inherently a multidisciplinary problem—choosing technically and economically feasible interventions. It is also inherently a problem that must consider the entire supply and demand chain because choices made by participants from the farm to the consumer level affect the amount of protection from foodborne illness ultimately achieved by the system.

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